Geol Survey

NEARSHORE GEOLOGY AND GEOLOGIC PROCESSES ALONG THE ILLINOIS SHORE OF LAKE MICHIGAN FROM WAUKEGAN HARBOR TO WILMETTE HARBOR

Contribution to the U.S. Army Corps of Engineers
Illinois Shoreline Erosion
Interim IV Study

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EXECUTIVE SUMMARY

This report was prepared by the Illinois State Geological Survey (ISGS) at the request of the U.S. Army Corps of Engineers Chicago District. It is a contribution to the Corps' Interim IV Study which concerns storm damage and coastal erosion along 22 miles of Illinois shore of Lake Michigan from Waukegan Harbor to Wilmette Harbor. Objectives of this report are to evaluate nearshore erosion and accretion trends, to assess the coastal impacts of the two federal coastal projects in the study area (Waukegan Harbor and the harbor at the U.S. Navy Great Lakes Naval Training Center), and to prepare a preliminary sediment budget for the nearshore.

The study area is primarily a glacial-bluff coast with a thin lens of sand and gravel in the beach and nearshore. Natural and human-induced coastal processes are contributing to the depletion of beach and nearshore sediments. As sand cover is removed from the lakebed, glacial till becomes exposed and can be downcut.

Bathymetric comparisons document that the nearshore sand loss has been ongoing for most of the 20th century, but in the past 20 years these erosional processes have increased in extent, degree, and rate. Between 1910 and 1974 nearshore erosion dominated from Waukegan Harbor to Highland Park, and nearshore accretion dominated southward to Wilmette. Data from 1989 to 1994 indicate that beach and nearshore erosion now dominate the entire study area. In 1974 sand was depleted from the nearshore in a few isolated areas, primarily downdrift of Great Lakes Harbor. By 1994, sand was thinned or stripped from much of the nearshore between Waukegan Harbor and Lake Forest. Between 1974 and 1994, lakebed exposures of till downdrift of Great Lakes Harbor were downcut at rates up to 0.19 to 0.27 ft/yr, and in a localized area up to 0.35 ft/yr. These rates are comparable to rates of till erosion documented downdrift of the Corps-maintained harbor at St. Joseph, Michigan.

Evaluation of coastal impacts associated with Waukegan Harbor indicates that the most detrimental coastal impact has been the offshore (deep-water) disposal of sediment dredged from the harbor entrance. From 1889 through 1976, and then again in 1982, dredge spoil was dumped about 2.5 miles offshore. This practice permanently removed a total volume (bin measure) of 2,492,754 cu yds from the Illinois littoral zone . First in 1977, and consistently since 1984, dredge spoil from the harbor has been artificially bypassed to a downdrift nearshore disposal site. A total volume (bin measure) of 578,647 cu yds has been bypassed as of 1994. Although this provides some nearshore nourishment, it is insufficient to alleviate the severe nearshore erosion occurring downdrift of this harbor.

A 50-year projection of nearshore erosional trends results in the possibility of severe coastal damage. If nearshore profiles continue to steepen, deeper water will be closer to shore which will allow greater wave energy to impact the shore and cause greater storm damage. Loss of sand and downcutting of till will result in the undermining of shore-defense structures. Without remedial action such as beach/nearshore nourishment, many of the existing shore structures could fail during the next 50 years. Rapid and severe recession of the coastal bluffs could follow.

SECTION 1 INTRODUCTION

PURPOSE AND SCOPE

1.1 This report was prepared by the Illinois State Geological Survey (ISGS) under contract to the U.S. Army Corps of Engineers Chicago District as a contribution to the Corps-sponsored study entitled: Illinois Shoreline Erosion Interim IV. The Corps' study, here referred to as the Interim IV study, concerns coastal storm damage, coastal flooding, and coastal erosion along 22 miles of the Illinois shore of Lake Michigan from Waukegan Harbor at the City of Waukegan southward to Wilmette Harbor at the City of Wilmette (Fig. 1.1). The Interim IV study has three objectives:

> 1) to determine the extent of shoreline impacted by storm damage in the study area, evaluate how these impacts will change over the next 50 years, and quantify those impacts in monetary terms;
>
> 2) to determine what mitigation measures would alleviate or minimize these impacts;
>
> 3) to determine whether a federal interest exists in a storm-damage reduction project.

1.2 This ISGS report focuses on the nearshore coastal geology and coastal-sedimentary processes of the study area. Because of net littoral sediment supply and transport, the shore from Waukegan north as far as Kenosha, Wisconsin is also of interest (Fig. 1.1). Three specific issues are addressed here:

1) <u>Evaluation of Areal Trends in Nearshore Erosion and Accretion</u>
Aerial photography, bathymetric data, dredge records, and profile data were used to identify major erosional and accretional areas, calculate rates of erosion and accretion, and compute volumetric changes with time.

2) <u>Evaluation of Nearshore Coastal Impacts Associated with Federal Coastal Structures</u>
Two large-scale federal coastal structures exist in the study area. These are the harbor facility built and maintained by the Corps of Engineers at Waukegan (primarily built between 1883 and 1906), and the harbor at Great Lakes Naval Training Center built and maintained by the U.S. Navy (breakwaters built in 1923). This report evaluates the nearshore erosional and accretional coastal changes that can be attributed to these structures. In addition, consideration is given to how the coast would have evolved if these structures had never been built. The report also reviews impacts associated with Forest Park Beach at Lake Forest. This facility is not a federal project, but federal permits are pending.

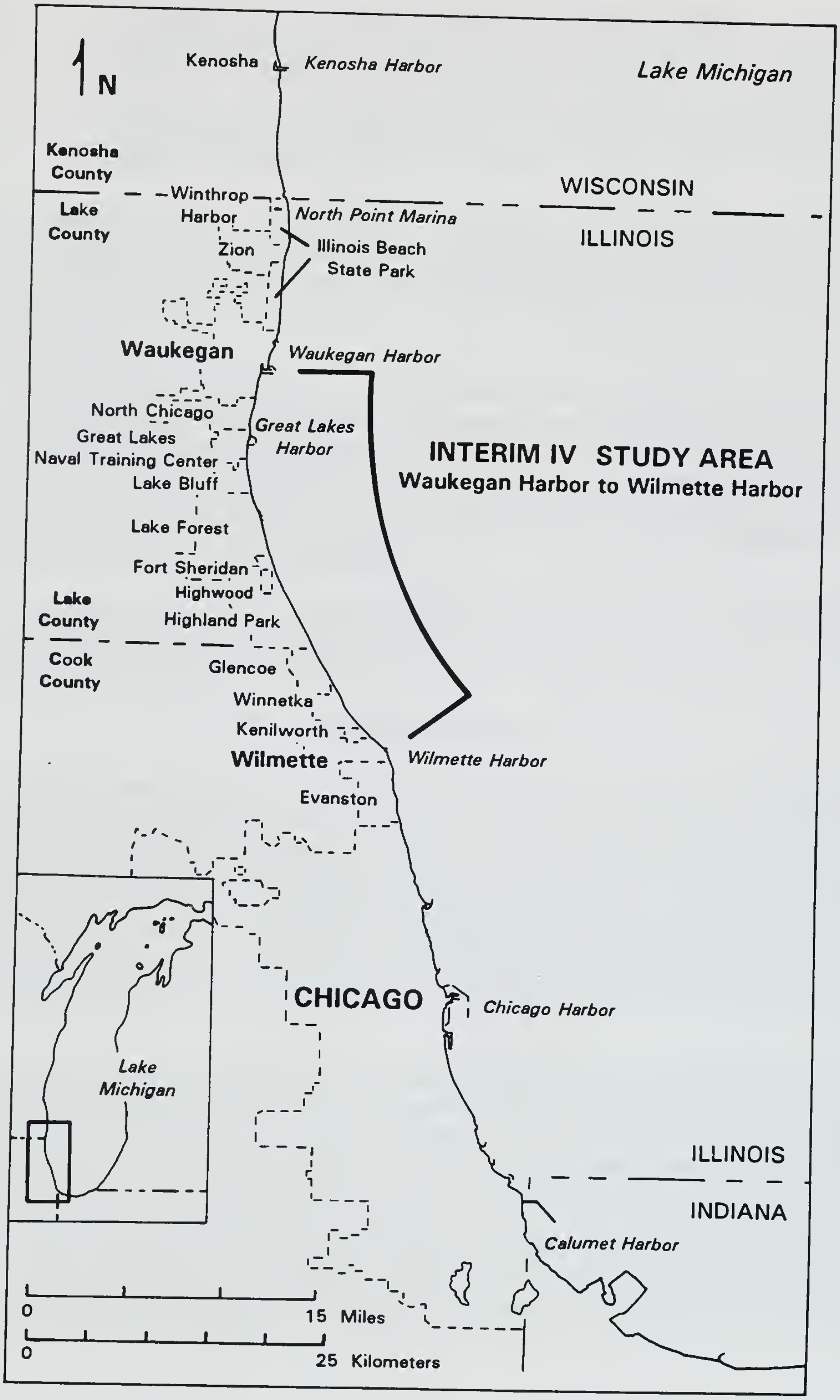

Figure 1.1. Location of the Interim IV study area along the Illinois coast.

3) <u>Development of a Preliminary Nearshore Sediment Budget</u>
Understanding the budget of littoral sediment input, storage, transport and loss for the study area is critical for designing nourishment plans, shore-defense strategies, or other mitigation measures to minimize storm and erosion damage. Data pertaining to the gain, loss, and transport of littoral sediment were compiled to develop a nearshore sediment budget for the study area.

1.3 This report is based on a compilation, synthesis, and interpretation of published and unpublished data. Data were compiled from several sources including annual reports of the U.S. Army Corps of Engineers, previous studies by the ISGS and other coastal researchers working in the study area, and data provided by the municipalities and federal facilities along the study area.

1.4 Constraints in time and funding prevented the ISGS from collecting any new data for this study. However, in early December 1994, under contract to the Corps of Engineers, data were collected by the U.S. Geological Survey (USGS) Branch of Atlantic Marine Geology. These included bathymetric data to map lake-bottom morphology, sidescan-sonar records to map the lake-bottom distribution of sand and till, and sub-bottom seismic reflection data to determine thickness of sand over till (Foster *et al.*, 1995). Components of these USGS data have been incorporated in this report where appropriate.

1.5 To facilitate application to Corps of Engineers projects, all units in this report are in U.S. customary units (*i.e.*, feet, miles, yards). Table 1.1 provides conversion factors for converting U.S. customary units to metric (S.I.) units.

PREVIOUS STUDIES

1.6 Comprehensive reports concerning historical beach and nearshore changes along the Illinois coast were completed in the 1950s by the U.S. Army Corps of Engineers (1953) and the State of Illinois Division of Waterways (1958). These two studies are benchmark reports for the documentation of coastal change along the Illinois lakeshore. Tetra Tech (1978, 1979, 1980) performed an analysis of shoreline erosion and accretion trends for the Illinois coast that includes this area. The U.S. Army Corps of Engineers Chicago District previously completed a draft feasibility study for the Interim IV study area (U.S. Army Corps of Engineers, 1989). That report summarizes many of the coastal characteristics and erosion problems of the study area.

1.7 Recent investigations focusing on the coastal geology and coastal processes in southern Lake Michigan are summarized in a series of papers published in a 1994 Special Volume of the Journal of Great Lakes Research. These studies included evaluating the coastal geomorphology (Chrzastowski *et al.*, 1994) and geologic framework (Foster and Folger, 1994), documenting thickness and offshore extent of coastal sand resources (Shabica and Pranschke, 1994), measuring rates of historical bluff erosion (Jibson *et al.*, 1994), and determining how ice contributes to coastal erosion (Barnes *et al.*, 1994). An ongoing investigation within the study area concerns annual coastal monitoring at Lake Forest to determine beach and nearshore accretion and erosion associated with Forest Park Beach (Chrzastowski and Trask, 1992, 1994; Trask and Chrzastowski, 1993, 1995).

Table 1.1. Factors for converting from U.S. customary to metric.		
U.S. CUSTOMARY	CONVERSION FACTOR	METRIC
	Length	
inch	2.54	centimeter
foot	0.3048	meter
yard	0.9144	meter
mile	1.609	kilometer
	Area	
square foot	0.0929	square meter
square yard	0.8361	square meter
square mile	2.59	square kilometer
acre	0.4047	hectare
	Volume	
cubic foot	0.0283	cubic meter
cubic yard	0.7646	cubic meter
To convert from U.S. customary units to metric units, multiply by the conversion factor in the central column.		

1.8 Much of the data compilation for this report relies on time-series comparisons of bathymetric data. Three sets of historical bathymetric maps deserve special mention. Two of these are the bathymetric/topographic maps prepared by the U.S. Lake Survey in 1872/73 and in 1909 and 1910/11. For each of the two survey periods, three map sheets cover the area from Waukegan to Wilmette at a scale of 1:20,000. Complete citations for these maps are given in the References (see references for U.S. Lake Survey). These maps provide nearshore soundings and contours that document the lake-bottom morphology prior to much of the modern coastal development in the region. These baseline data can be compared with more recent data to determine the extent and degree of historical coastal change.

1.9 The third map set is based on bathymetric profile data collected between 1974 and 1976 by the ISGS (Collinson *et al.*, 1979). Bathymetric maps were prepared at a scale of 1:4800. Although more recent profiling has been done in selected areas, these maps provide regional coverage. The timing of these bathymetric data is particularly significant for this study because in 1977 the practice of disposing dredge spoil at Waukegan Harbor began to change from deep-water offshore disposal to nearshore disposal. Thus, when compared with data from the U.S. Lake Survey, the ISGS data provide a means of evaluating lake-bottom changes during the time of downdrift sand deprivation due to deep-water disposal.

SECTION 2 STUDY AREA SETTING

GEOGRAPHIC DESCRIPTION

2.1 The Illinois coast of Lake Michigan from the entrance to Waukegan Harbor at Waukegan to the entrance of Wilmette Harbor at Wilmette is 22 miles long and comprises 35 percent of the total 62 miles of Illinois shoreline. The plan view of the coast is curvilinear forming a broad arc, and compass directions perpendicular to the shoreline range from east-southeast near Waukegan to northeast near Wilmette (Fig. 1.1). The configuration of this coast is strongly influenced by past glacial history (see section 2.17).

2.2 Nine municipalities are located along the lakeshore between Waukegan and Wilmette. The municipality with the longest lakeshore is Highland Park, having 4.7 miles; Kenilworth has the shortest municipal lakeshore, totaling 0.5 miles. The City of Highwood is an inland municipality south of Fort Sheridan that maintains a few hundred feet of shoreline between Fort Sheridan and Highland Park along a municipal water plant. Along the shore of each municipality is at least one lakeshore park/beach, a municipal waterworks, and/or a municipal sewage treatment facility. Most of the study area is occupied by low-density, private residential property.

2.3 Two federal properties along the reach are the U.S. Navy's Great Lakes Naval Training Center and the U.S. Army's Fort Sheridan. The Naval Training Center contains about 7,700 ft (1.5 miles) of shoreline and includes a breakwater-defended harbor that totals 104 acres. In terms of area, this is the largest harbor on the Illinois shore north of Chicago. Fort Sheridan has 5,700 ft (1.1 miles) of shoreline.

COASTAL GEOMORPHOLOGY

Geomorphic Divisions

2.4 Three different upland types occur in the study area (Fig. 2.1). From north to south, these are a low-lying beach-ridge plain, a bluff coast, and a coast along a relict lake plain that formed the lake bottom during higher levels of ancestral Lake Michigan.

2.5 ***Beach-ridge plain:*** The Zion beach-ridge plain is a coastal sand plain that originates along the Wisconsin coast south of Kenosha and extends southward to North Chicago on the Illinois shore (Fig. 2.2). Most of this beach-ridge plain in Illinois is within the North and South Units of Illinois Beach State Park. Maximum width of the plain is about 1.2 miles, which occurs within the state park. The landward margin of the beach-ridge plain consists of a relict coastal bluff that was intercepted by waves prior to the southward advance of the plain. Elevations across the plain are generally no more than about 10 ft above mean lake level. Waukegan Harbor was built within the depositional zone at the southern end of the plain. South of Waukegan Harbor the width of the plain is less than half that occurring north of the harbor. The southern limit of the plain is along the shore at North Chicago.

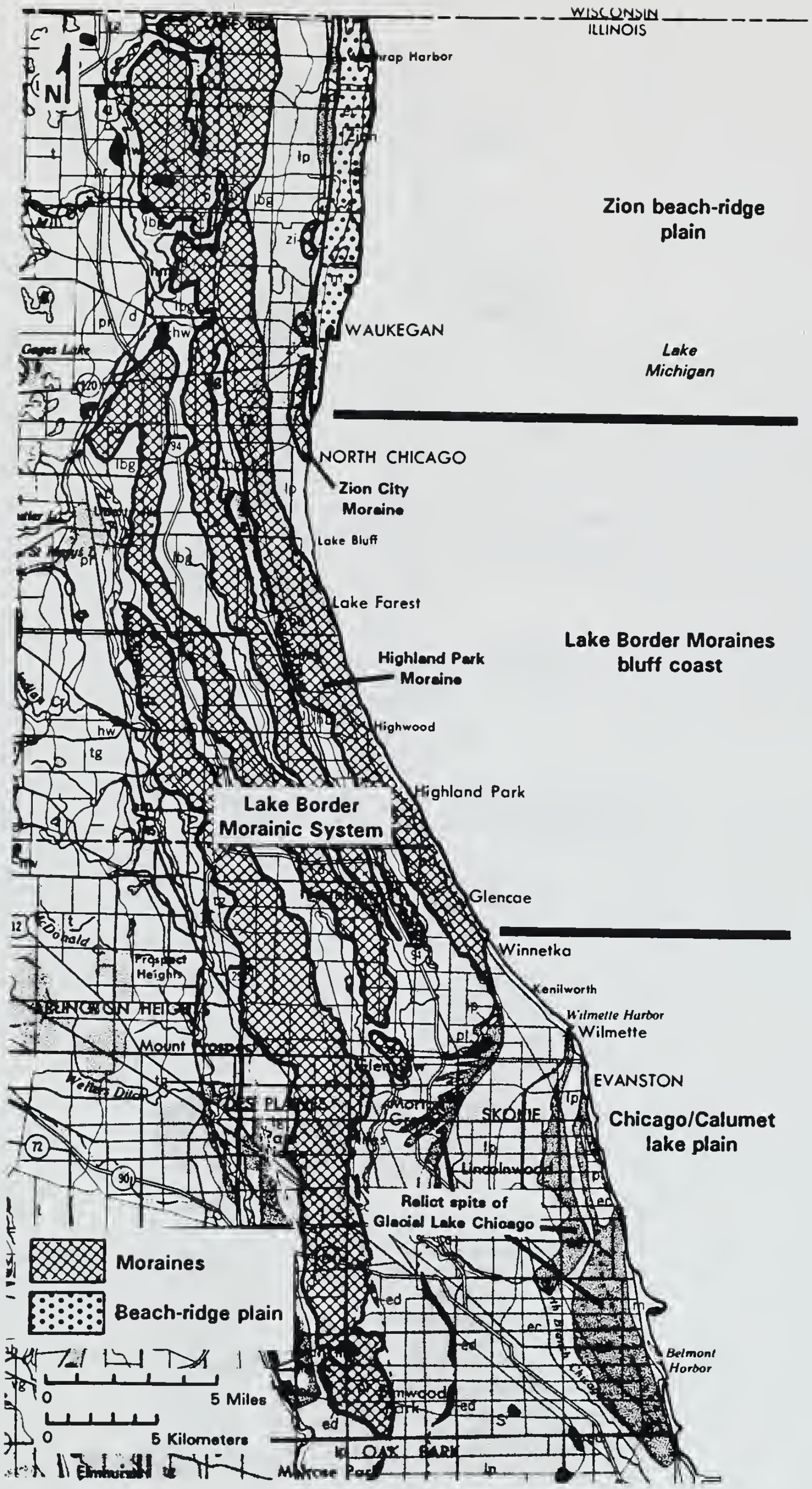

Figure 2.1. Coastal geomorphic divisions along the study area (modified from Willman and Lineback, 1970).

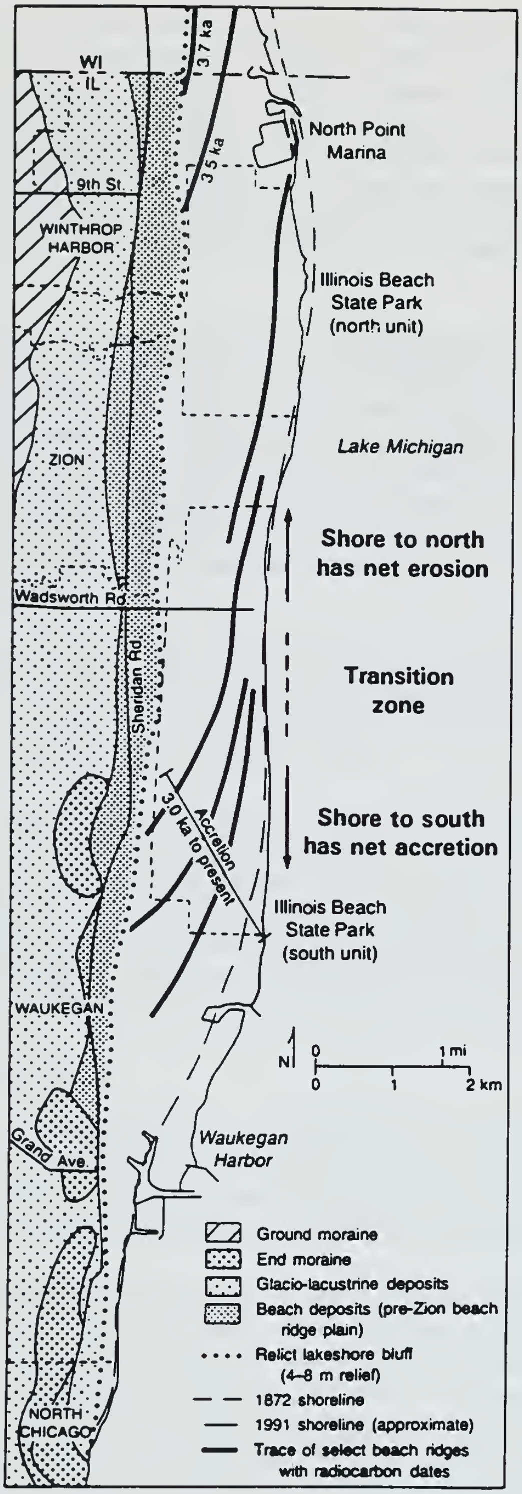

Figure 2.2. Extent of the Zion beach-ridge plain along the northern Illinois coast. Radiocarbon ages are shown for selected beach ridges in thousands of years (ka) (from Chrzastowski *et al.*, 1994).

2.6 For several thousand years this coastal feature has been migrating southward by the process of net southerly littoral transport. Erosion has been occurring in the northern (updrift) reaches and deposition has been occurring in the southern (downdrift) reaches. Based on radiocarbon dating of basal marsh deposits, the beach ridges first advanced southward across the Illinois-Wisconsin state line about 3700 years ago (Larsen, 1985). Illinois Beach State Park preserves numerous curvilinear beach ridges and dunes that record the relict shorelines from the southward advance of the plain. Within the South Unit, a transition zone occurs along the shore between net erosion northward of the zone, and net accretion southward of the zone (Fig. 2.2).

2.7 ***Bluff coast:*** A bluff coast extends from North Chicago southward to the vicinity of Lloyd Park in Winnetka. The bluff coast is formed where the coast intercepts the Highland Park Moraine of the Lake Border morainic system, and at North Chicago a short reach of the Zion City Moraine and relict glacial-lake deposits (Fig. 2.1). The bluffs consist of gray to brown glacial till interbedded with glacial-lake sediments of clay, silt, sand and sandy outwash. Silt and clay are the dominant bluff materials (Clark and Rudloff, 1990). Average grain-size distribution for the till is 10 percent sand, 42 percent silt, and 48 percent clay (Lineback, 1974). In general, only about 10 to 15 percent of eroded bluff materials are coarse enough to provide beach sediments.

2.8 Bluff heights relative to mean lake level are variable, but are generally in the range 70 to 90 ft high. The maximum heights occur at Highland Park. The bluff slopes range from 25 degrees to near vertical. The bluffs are incised by a series of V-shaped ravines occupied by intermittent streams that drain the uplands to the west.

2.9 ***Lake plain:*** In the southern part of the study area, along the shore at Winnetka, Kenilworth and Wilmette, the coast intercepts the northernmost part of a broad, relict lake plain that continues south and east to near the Indiana-Michigan state line. This Chicago-Calumet lake plain formed the bottom of Lake Michigan when lake levels were higher in the recent geologic past (Chrzastowski and Thompson, 1994). The shore from Winnetka to Wilmette intercepts a high part of this plain, and thus low bluffs (20-25 ft high) occur along this reach. In terms of geologic setting, however, this reach is distinct from the bluff coast to the north.

Beach and Nearshore Sediments

2.10 The beaches from Waukegan south to Wilmette have a variety of material sizes. Size differences can occur across very short distances where structures such as groins have trapped coarser material but have allowed the continued transport of finer grain sizes. Grain size varies from clean sand to mixtures of sand, pebbles and cobbles, to pure pebbles and cobbles.

2.11 Sediment distribution across the nearshore was recently mapped by Foster and Folger (1994). Data were also collected by the USGS using sidescan sonar as part of this Interim IV study (Foster *et al.*, 1995). The sediment distribution is complex and variable. From Waukegan south to Lake Forest is a combination of patchy sand veneers and broad areas of exposed till. Along this reach, landward of the 20-foot isobath, sand thicknesses are generally less than 3 ft. In deeper water, several broad areas have sand thicknesses up to 10 ft (Foster *et al.*, 1995). From Lake Forest south to Glencoe, sand deposits are patchy, and much of the bottom is till or lag gravel and sand from eroded till. From Glencoe south to Wilmette, sand becomes more abundant across the nearshore, and till exposures are the exception.

2.12 Along the bluff coast, the beach and nearshore deposits occupy a narrow zone extending from the toe of the bluff to several hundred to thousands of feet offshore where the

sand pinches out or becomes a veneer (Fig. 2.3). Probing of beach and nearshore sand thicknesses along the bluff coast indicates that maximum sand thicknesses are generally no more than about 5 to 7 ft (Shabica *et al.*, 1991; Shabica and Pranschke, 1994). Thicker deposits occur in some of the areas of entrapment near structures; for example, updrift of the north breakwater at Great Lakes Harbor, thicknesses reach 10 to 12 ft.

2.13 The thickest deposits of coastal sand occur along the Zion beach-ridge plain. In cross section the sand plain is lenticular (Fig. 2.3) with maximum thickness of 25 to 30 ft occurring along the State Park shoreline and thinning both landward and lakeward (Fraser and Hester, 1974; Hester and Fraser, 1973).

Nearshore Bathymetry

2.14 Lake-bottom profiles are generally uniform along the entire study area. No shoals, troughs, escarpments, or rapid changes in slope occur. Bathymetric contours are generally parallel to the coast. At a distance of one mile offshore the depth rarely exceeds 30 ft Low Water Datum (LWD). Lakeward of the nearshore sand body, the lake bottom is an irregular surface of glacial till that may locally include hummocks, mounds, or closed depressions that result in relief several feet above or below the surrounding lake bottom.

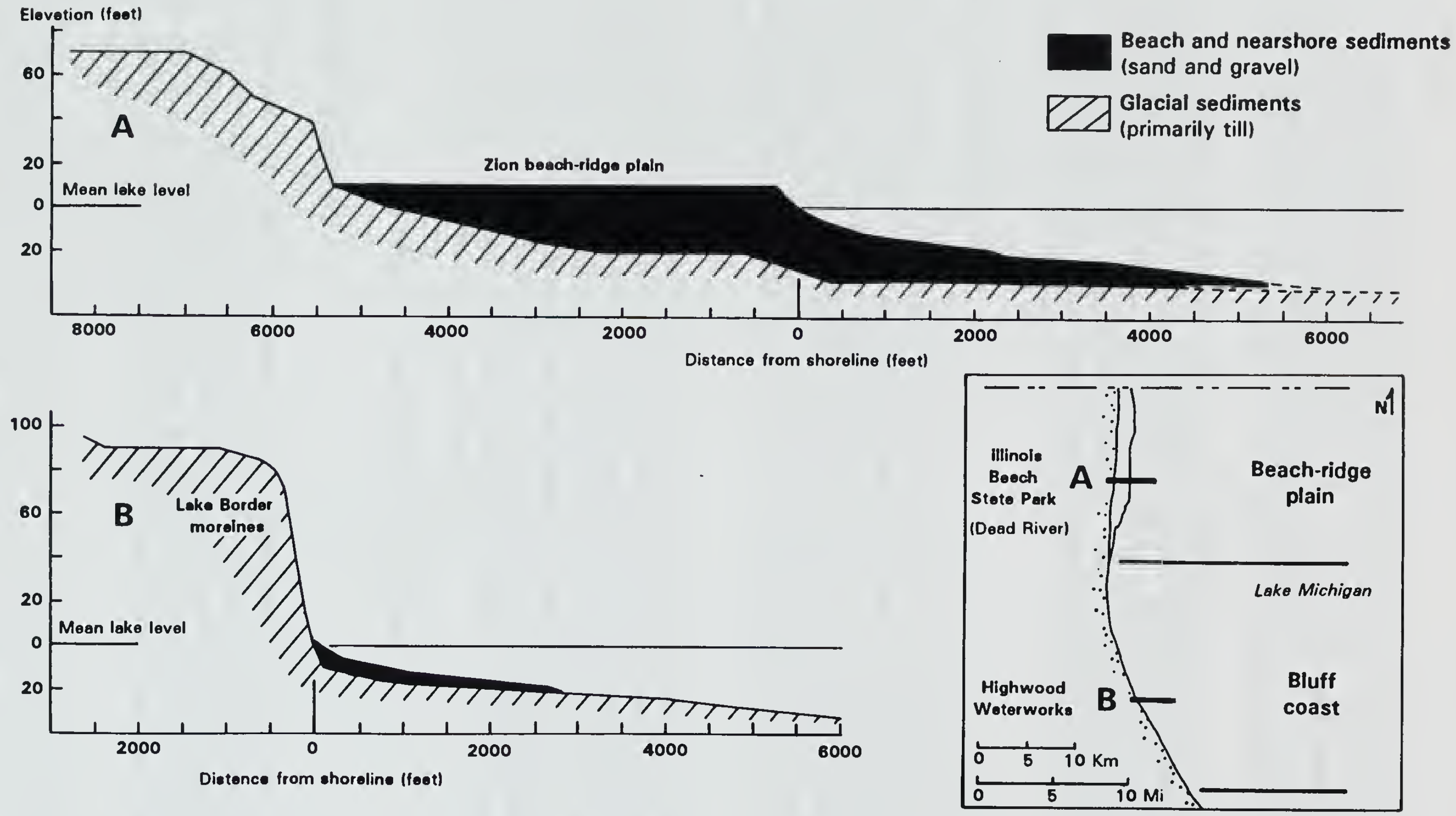

Figure 2.3. Cross sections of the Illinois coast for a location along the Zion beach-ridge plain (A) and the bluff coast at the Highwood waterworks (B).

GEOLOGIC HISTORY

Lake-Level History

2.15 Fluctuations in lake level are a critical component in the erosional and accretionary processes along this coast. On an annual basis, lake level varies by about one foot with high water occurring in summer, and low water in winter. Since official lake-level records were begun by the U.S. Lake Survey in 1860, the extreme range of monthly mean elevations is 6.3 ft between the historical low water in March 1964 and historical high water in October 1986.

2.16 From the time that glacial ice first receded from this area (about 14,000 years ago) until about 4,000 years ago, lake levels fluctuated widely. A series of successively decreasing high-lake levels occurred with stands reaching as much as 60 ft above present lake level (Hansel *et al.*, 1985). In the last 2,500 years a rather uniform mean lake level has endured, and it has been during these past 2,500 years that coastal processes have been most influential in shaping the coast that we know today.

Coastal Form and Geologic History

2.17 The arcuate form of this coastal reach has been strongly influenced by the regional glacial history. The shoreline configuration mimics the series of juxtaposed recessional moraines that form the Lake Border Morainic System (Fig. 2.1). These moraines correspond to a series of marginal positions of the glacial ice lobe as it was receding from southern Lake Michigan. Coastal erosion into these moraines has resulted in the bluffs that dominate this coast. Former shoreline and bluffline positions of the recent geologic past were in what is now the nearshore or offshore zone.

2.18 The similarity between the moraine orientations and the orientation of the bluff coast attests to the youthfulness of this coast. This coast is in the early stages of being modified by wave processes to a form in equilibrium with regional wave dynamics and littoral sediment supply. If no human activity were to interfere with the coastal erosion processes, and historical lake levels were maintained, over thousands of years the bluff coast would erode landward to an equilibrium position (Rovey and Borucki, 1994). During this process, rates of erosion would decrease with time. The final equilibrium position could be several hundred to several thousand feet landward of the present position.

LITTORAL TRANSPORT PROCESSES

Net Littoral Transport Direction

2.19 The direction of net littoral transport in the study area is southward. Because the longest fetch is from the northeast quadrant, northerly waves have the greatest energy and net influence. The greater energy of northerly waves produces the net southward transport. The net southerly transport is documented by accretion on the north (updrift) side of groins, breakwaters, jetties, and other shore-perpendicular structures. Southerly waves cause intermittent reversals in drift direction.

2.20 Exceptions to the net southerly transport occur on the south side of Waukegan Harbor and the harbor at Great Lakes Naval Training Center. In both cases shore structures extend far enough lakeward to produce a localized "shadow zone" for northerly waves, and therefore southerly waves have the net influence and produce a localized net northerly transport.

2.21 On the south side of Waukegan Harbor, this net northerly transport has resulted in a small beach built in the cove bounded by the upland and the south breakwater for the small boat harbor. On the south side of Great Lakes Harbor, the net northerly transport maintains a crescent-shaped beach built in the cove bounded by the bluffs and the landward end of the harbor's south breakwater. In both cases, these beaches are widest at the north and pinch out at the south consistent with the northerly net littoral transport.

Defining Littoral Cells

2.22 To evaluate the supply, transport, and entrapment of bedload littoral sediments along a coastal reach, it is useful to identify the limits of individual littoral cells or compartments. In natural settings, the boundaries of littoral cells typically occur at headlands, at embayments, or at some pronounced change in the orientation of the shoreline. Along coasts that have been significantly modified with structures for shore defense or other coastal engineering, these coastal structures typically form the cell boundaries.

2.23 In work along the Indiana coast, Wood and Davis (1986) and Wood *et al.* (1988) classified structures based on the degree to which they limit littoral transport. The following hierarchy was defined:

> ***Primary structures:*** These structures are total to near-total barriers to littoral transport. Along the southern Lake Michigan coast, such structures need to extend to about 20 ft depth, which is the regional depth of closure (Hallermeier, 1983).
>
> ***Secondary structures:*** These structures allow some bypass, but may trap up to 75 percent of the littoral supply.
>
> ***Tertiary structures:*** These are structures that trap less than 10 percent of the transport. Most groins typically fall in this category.

2.24 These types of boundary structures can be used to define a hierarchy of littoral cells. Two qualifications to the hierarchy are important. First, because artificial bypass (*i.e.*, bypass of dredged material) may be a means for littoral sediment to continue in transport around primary structures, these major structures can be classified as secondary rather than primary if artificial bypass occurs. Second, the classification of a structure and the boundaries of a littoral cell can change with time. For example, initially a groin, jetty, or harbor facility may be a near-total barrier to littoral drift. With time, however, accretion reaches capacity and allows natural bypass; this will change the classification of the structure from primary to secondary and eventually to a tertiary structure as near-total bypass occurs.

2.25 Prior to human modifications, all of the Illinois coast was part of a continuous littoral stream that originated along the Wisconsin coast near Sheboygan or possibly near Manitowoc and terminated along the central Indiana shore (Chrzastowski and Thompson, 1994). Historical development along the Illinois coast has segmented it into a series of primary and secondary littoral cells. The locations of present-day littoral cell boundaries along the Illinois lakeshore have been defined by Chrzastowski *et al.* (1994) and are summarized below.

Littoral Cell Divisions

2.26 The Interim IV study area from Waukegan to Wilmette incorporates the central part of a primary littoral cell along the western shore of Lake Michigan that extends from Kenosha, Wisconsin to the north lakeshore of Chicago. Within this reach, structures associated with harbors, marinas, and other lakeshore development projects divide this primary cell into nine secondary cells.

2.27 Figure 2.4 shows the location of the primary and secondary cell boundaries for the study area. The updrift boundary of the primary cell is Kenosha Harbor, Wisconsin. Jetties at the harbor entrance and disposal of dredge spoil combine to make this a total to near-total barrier to littoral drift. The terminus of the primary cell is updrift of the shoreline protrusion formed by the Montrose Peninsula on Chicago's northside lakeshore.

2.28 The following section describes the boundaries of these primary and secondary littoral cells from north to south.

2.29 ***Kenosha Harbor (Wisconsin)*** Jetties and an offshore detached breakwater defend the harbor entrance. No artificial bypassing of dredge spoil occurs. Prior to and including 1969, dredge spoil was disposed of in deep water. From 1976 through the most recent dredging in 1987, spoil was placed in a confinement area on the south side of the harbor. This confinement area reached capacity following the 1987 dredging. No dredging occurred between 1988 and 1994. As of this report (1995), new disposal sites are being considered.

> Note: Although Kenosha Harbor is here classified as a primary cell boundary, shoaling at the harbor entrance can reduce depths such that natural bypass can occur, and the facility then acts as a secondary or tertiary cell boundary. When natural bypass occurs, the primary cell boundary occurs to the north at either Racine Harbor or the harbor complex at Milwaukee.

2.30 ***Prairie Harbor (Wisconsin)*** This privately owned small-boat harbor is located adjacent to the Wisconsin-Illinois state line. A rubble-mound jetty protects the north side of the harbor entrance; a steel-sheetpile jetty is on the south side. Depths at the jetty ends and across the entrance channel are no more than 12 ft LWD, permitting natural bypass. The entrance channel is dredged yearly or twice yearly. Spoil is stockpiled inland or used as updrift beach nourishment. No artificial bypass is done.

2.31 ***North Point Marina*** Construction of this state-owned marina began in 1987 and was completed by 1989, making this the most recent major coastal structure to be added to the Illinois coast. A pair of arcuate rubble-mound breakwaters defend the lakeward perimeter of the marina basin. The north breakwater reaches farther offshore and forms a partial barrier to littoral transport. Sand that bypasses this breakwater can potentially accumulate in the marina entrance. In spring 1995, for the first time, a permit application was made for maintenance dredging of the marina entrance area.

2.32 ***Commonwealth Edison Waukegan Power Plant*** The coal-fired power plant at Waukegan has a cooling-water basin that is open to the lake. On the south side of the basin opening is a lakeward-projecting, steel-sheetpile groin that houses a cooling-water intake pipe. The groin extends to offshore depths no more than about 10 ft LWD, allowing natural bypass. The nearshore updrift of the groin is a persistent shoaling area that is dredged to assure proper depths for recycling cooling water. Recent dredge disposal has been placed updrift along the beaches or nearshore of Illinois Beach State Park.

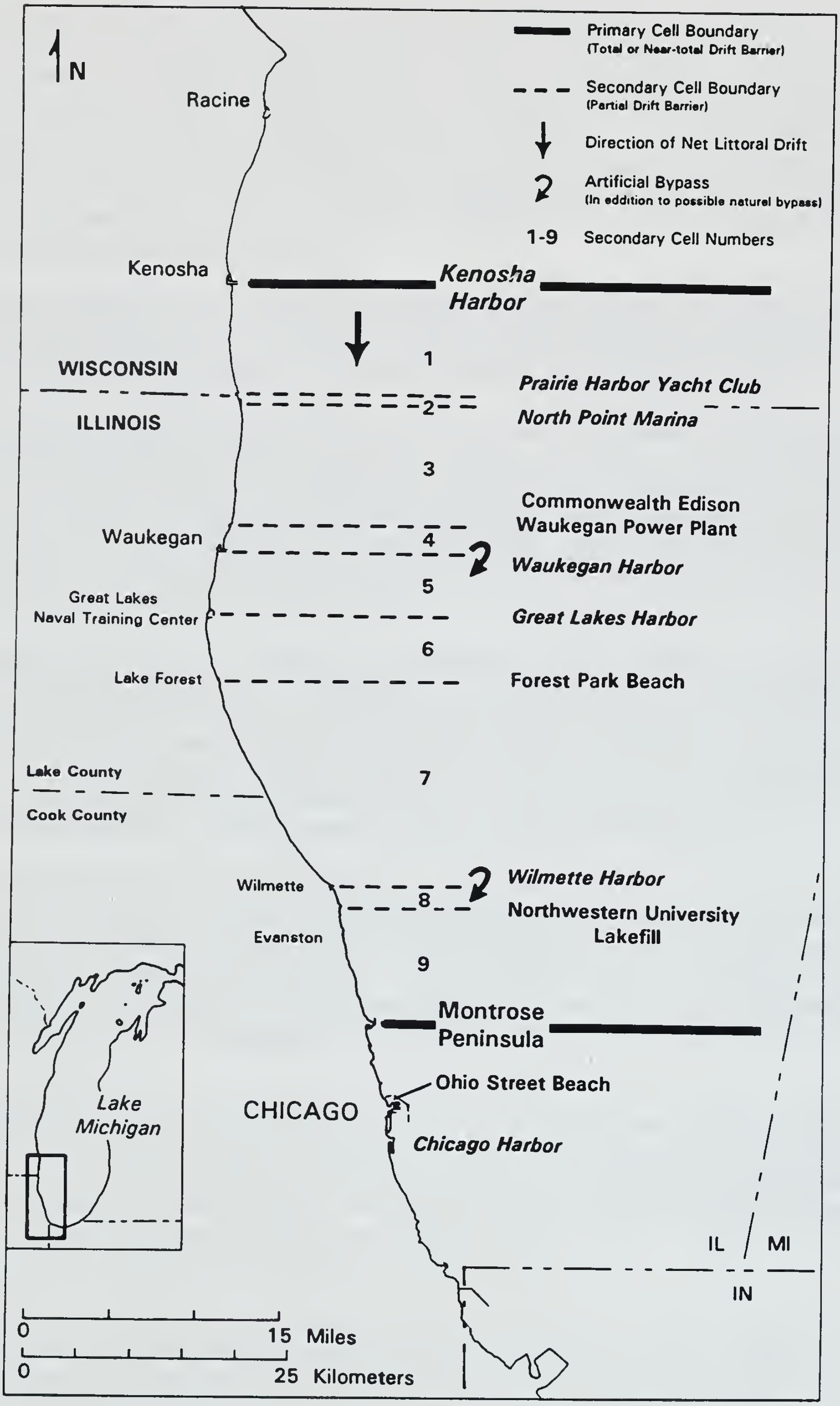

Figure 2.4. Boundaries of littoral cells along the coast of southern Wisconsin and northern Illinois. Cell boundaries are defined for conditions of natural and artificial (dredge spoil) bypass that exist as of 1995.

2.33 ***Waukegan Harbor*** The jetties, shore-attached breakwater, and navigation channel at Waukegan Harbor combine to form the largest barrier to littoral drift along the Illinois shore north of Chicago. The jetties extend to a lake depth of about 20-25 ft LWD; project depth along the entrance channel is 23-25 ft LWD (Bottin, 1988). Maintenance dredging is done every one or two years. Since construction of the modern harbor in the early 1900s until the late 1970s, this was a primary cell boundary because dredge material was disposed of in deep water 2.5 miles offshore. First in 1977, then consistently since 1984, dredge disposal has been in the nearshore to the south of the harbor. Because of this artificial bypass the harbor is here classified as a secondary barrier.

> Note: Evan during tha tima of offshora dradga disposal, soma littoral sadimant was capabla of natural bypass of the harbor antranca. This process was praviously discussad by Krumbein and Ohsiek (1950). In a subsaquent saction of this raport wa nota that comparison of bathymetric data from 1910 and 1974 indicatas an accrational araa that also documants a natural bypass of tha harbor antranca.

2.34 ***Great Lakes Naval Training Center Harbor*** The pair of rubble-mound breakwaters that form the harbor at this U.S. Navy base were constructed in 1923. For some time after construction, the harbor was a near-total barrier to littoral drift. Entrapment occurred along the beach and nearshore updrift of the harbor, around the north breakwater and extending downdrift from the harbor entrance, and inside the harbor. Comparisons of bathymetric data from 1910 through 1992 presented in this report provide evidence that natural bypass is now occurring and has been since at least 1974.

2.35 ***Forest Park Beach*** This facility was constructed in 1986 and 1987 by the City of Lake Forest to provide shore protection and recreation. An arcuate series of shore-attached rubble-mound breakwaters form four beach cells and a small-boat launch basin. The facility has a relatively small lakeshore footprint and extends offshore about 410 ft from the pre-construction shoreline. Since construction, accretion related to natural bypass has occurred in several of the beach cells and around the lakeward perimeter. Annual dredging is performed for the small-boat launching basin. Dredge spoil is placed in the downdrift nearshore.

2.36 ***Wilmette Harbor*** This small-boat basin occupies an artificial embayment that provides lake water to the up-current end of the North Shore Channel that maintains southerly flow in the Chicago River system. A partial barrier to littoral drift is created by jetties and the entrance channel, which is intermittently dredged. Natural bypass occurs. Dredging provides an artificial bypass of 90 percent of the dredge spoil to the beach and nearshore immediately downdrift of the harbor. Backpassing of 10 percent is provided to the updrift beach at Gillson Park.

2.37 ***Northwestern University Lakefill*** This lakefill was built between 1964 and 1966 for the expansion of the university campus. For several years after construction the lakefill acted as a near-total barrier to littoral drift. Accretion advanced around the lakefill perimeter as a pathway developed for natural bypass. Profile data collected in the late 1980s suggest that this pathway was complete by that time (Shabica *et al.*, 1991). Updrift accretion has apparently slowed, suggesting the fillet is at or near capacity.

2.38 ***Montrose Peninsula*** The Montrose Peninsula extends about 1 mile lakeward of the pre-lakefill shoreline. Depths along the eastern side of the peninsula are 18-20 ft LWD. The hook-shaped groin extending northward from the eastern end of the lakefill is a barrier to littoral transport around the peninsula. The terminal area for littoral transport is a broad, nearshore accretion area updrift of the peninsula. Probing in this nearshore area has measured sand thicknesses of as much as 15 ft (Pranschke and Brown, 1988).

2.39 ***Chicago Harbor/Ohio Street Beach*** Some littoral sand may bypass the Montrose Peninsula. Sand migrating around the peninsula can potentially be transported as far southward as Ohio Street Beach inside the Chicago Outer Harbor. No littoral transport can continue farther south due to the water depths around the lakefills forming the Chicago Central Filtration Plant and Navy Pier.

SECTION 3 AREAL TRENDS IN EROSION AND ACCRETION

GENERAL STATEMENT

3.1 The coastal reach of the Interim IV study is undergoing major nearshore changes as a result of human activity and natural processes. Areal trends in erosion and accretion across the nearshore are becoming the prime factor determining erosional responses along the beaches and bluffs. In evaluating coastal storm damages of the past, and in projecting future damages, these trends in erosion and accretion typically need to be considered for the uplands, the beaches and shoreline, and the nearshore. The bluffs and shoreline are briefly discussed here, but the emphasis is on trends in the nearshore area.

OVERVIEW OF RECESSIONAL CHANGES

Bluff Recession

3.2 The most recent and thorough investigations of bluff erosion along the coastal bluffs from Waukegan to Wilmette were completed by Jibson *et al.* (1994). They used historical maps and aerial photography to map bluff-line retreat for the intervals 1872-1937 and 1937-1987. This 115-year record spans the time from when this coastal reach had little if any coastal engineering to a time when much of the coast is dominated by groin fields, revetments, bulkheads, and riprap.

3.3 Jibson *et al.* (1994) concluded that the average rate of retreat for the entire study area was in the range 7.8 to 9.8 inches/yr (0.65-0.82 ft/yr). Assuming these rates apply over the next 50 years gives a predicted average bluff retreat of 32.5 to 41 ft. Few of the properties along this coastal reach have sufficient set-back to accommodate such bluff recession rates. Thus human intervention would be necessary to prevent this bluff recession from occurring.

Shoreline Recession

3.4 Shoreline change maps for the study area have been produced by the U.S. Army Corps of Engineers (1953) for four time periods based on data collected in 1872/73, 1909/11, 1937/38, and 1946/47. The State of Illinois Division of Waterways (1958) produced shoreline change maps for data collected in 1872/73, 1946/47, and 1955, and made an overall comparison from 1872 to 1955. The maps of both publications are based on beach and nearshore profile data and compare shorelines referenced to a common datum of LWD. Between 1872 and 1955, shoreline recession was common along most of the study area but was locally negated by lakefills or accretion updrift of obstructions. The most severe shoreline recession during these 83 years was about 500 ft (~6 ft/yr) occurring downdrift of Great Lakes Harbor (State of Illinois Division of Waterways, 1958, Exhibit 5). Severe erosion was also identified in this area by Tetra Tech (1979).

3.5 No study has since occurred along the Illinois shore to create datum-corrected shorelines and from these determine shoreline recession rates. Chrzastowski and Read (1993) provide an inventory of maps and aerial photographs that could be used in a shoreline change study along the Illinois coast; Chrzastowski *et al.* (1993) evaluated possible mapping techniques for such a study, but no datum-corrected database was prepared. Producing such a database was beyond the scope of this Interim IV study.

Shoreface Recession

3.6 Shoreface recession refers to the landward translation of the upper part of the nearshore profile. Erosion in the nearshore will contribute to serious shore damages over the next 50 years. As erosion proceeds, the overall nearshore profile becomes steeper closer to shore, and this begins a feedback process allowing larger waves to intercept the shore and cause even greater erosion and additional profile steeping. The effects on the shore are reduction in beach width, undermining of shore structures and, where beaches and structures are absent, greater wave attack at the toe of the coastal bluffs.

3.7 The extent and degree of erosion that have occurred in the nearshore are discussed in the following sections, and are based on comparison of historical and recent bathymetric data. The most severe shoreface recession in the study area has occurred downdrift of Great Lakes Harbor.

NEARSHORE EROSION AND ACCRETION MAPPING METHODS

3.8 Three different bathymetric data sets were used to map nearshore erosion and accretion. These were; 1) data from U.S. Lake Survey for 1872/73 and 1909/10/11; 2) data from ISGS for 1974/75/76; and 3) data from USGS for 1994 (see sections 1.4, 1.8, and 1.9).

3.9 Defining the time intervals for map comparisons is necessary when calculating annual rates. These time intervals are complicated because most of the surveys were done over multiple years. To be consistent with previous work in profile and bathymetric comparisons along this shore (U.S. Army Corps of Engineers, 1953; State of Illinois Division of Waterways, 1958) all 1872/73 data is referenced to 1872, and the 1909 and 1910/11 data are referenced to 1910. The ISGS data along the study area was primarily collected in 1974, although some data were collected in 1975, primarily along the Highland Park shore. For consistency this report uses 1974 as the standard reference. The exception is for the interior of Great Lakes Harbor, where the survey year 1976 is used.

3.10 Different methods were required in generating erosion and accretion maps for the different data sets. Comparison of 1910 to 1974 data was done at a map scale of 1:10,000. At every 1 inch on the map (833 ft on the ground) a profile line was generated. One-foot depth increments were read from LWD contours drawn on the 1974 maps. Contours on the 1910 maps are in 6-ft intervals; these provided primary profile control, and a linear trend was assumed between points. The profile comparisons provided isopach control points of lake-bottom change which were plotted along each profile line. A 3-ft contour interval was used in areas of major lake-bottom change. A 1-ft supplemental contour was used in areas of less pronounced change. This assured that change volumes would not be overestimated in these areas (*i.e.*, a mid-contour value of 0.5 was more certain than 1.5). In the southernmost part of the study area (south of central Winnetka), the 1909 survey does not extend into the shallow nearshore, and data from the 1872 survey provided the historical baseline. For all of the nearshore comparisons up to 1974, a limit of lake-bottom change was assumed along a line drawn where bathymetric comparisons indicated a lakeward limit of change, or where the data comparisons did not extend far enough lakeward, along a line drawn within the depth range of 18 to 20 ft LWD based on the 1910 bathymetric data. The 1910 bathymetry was used because along much of the study area the 1974 (or 1975) data did not extend far enough lakeward to reach 18-20 ft LWD.

3.11 For comparison of the 1974 to 1994 data, plots of the two data sets with 1-ft LWD contours were overlaid at map scale 1:4800. Contour intercepts provided control points to generate 1-ft interval isopach maps. The 20 ft LWD contour from the 1994 survey was drawn as a reference. 1974-1994 lake-bottom changes were documented lakeward of the 20 ft LWD contour, thus indicating that any use of 18-20 ft LWD as an assumed lakeward limit of change is only an approximation.

Note: The isopach maps showing comparisons for 1910-1974 and 1974-1994 are generalized representations of lake-bottom changes. For the comparisons of the 1910 to 1974 data, the objective was to identify areas of major change and to quantify these changes within 1 to 3 ft. All of the isopach maps were done by hand. To assure consistency and a systematic interpolation between data points, a computer-assisted map comparison could improve the quality of the map comparisons.

NEARSHORE EROSION AND ACCRETION (1910-1974)

Map Distribution of Nearshore Erosion and Accretion

3.12 Figures 3.1 through 3.5 show the map distribution of 1910-1974 erosion and accretion plotted on USGS 7.5-minute topographic maps and reproduced at a scale of 1:48,000. Erosional areas are highlighted with a stipple pattern. The following discussions point out significant map patterns.

3.13 ***Waukegan Harbor Updrift (Fig. 3.1):*** The nearshore accretion immediately updrift of Waukegan Harbor can be attributed primarily to the barrier influence caused by the shore-attached north breakwater. Nearshore accretion greater than 6 ft was dominant, and a broad area included accretion in the range 9 to 12 ft. Localized accretion in the range 12 to 15 ft occurred against the north breakwater.

3.14 ***Waukegan Harbor to Great Lakes Harbor (Fig 3.1):*** Both accretion and erosion occurred between these two major coastal structures. Although the dredged channel at the approach to Waukegan Harbor was a major intercept of littoral sediment, natural bypass of the channel is evident by the lobe of accretion (shown by the 3- and 6-ft contours) extending up to 9000 ft downdrift from the harbor entrance. This zone of accretion was also documented by Tetra Tech (1978), who suggested that 50,000 to 95,000 cu yds/yr was bypassing Waukegan Harbor. Within this lobe, maximum accretion was in the range 6 to 9 ft. A small area of accretion near the mouth of Waukegan River was likely a result of a localized net northerly transport against the shore-normal structure to the north of the river mouth at the south end of the small-boat harbor.

3.14 Erosion dominated the nearshore zone extending from the Waukegan Harbor south jetty to about 3000 ft north of the north breakwater at Great Lakes Harbor. Tetra Tech (1978) show this area as one of accretion during the interval 1872-1960. However, they note that sediment bypassing Waukegan Harbor was deposited too far offshore to contribute to the littoral stream. Maximum erosion was slightly more than 6 ft but this was localized, occurring in a few isolated places. The map patterns and thicknesses of accretion and erosion suggest that natural bypass of Waukegan Harbor may have diminished the total erosional impacts in the southern part of the erosional zone along the North Chicago shore.

3.15 ***Great Lakes Harbor Vicinity (Figs. 3.1 and 3.2):*** Updrift accretion occurred as far north as Foss Park, located about 4000 ft north of the north breakwater. This zone of updrift accretion was also documented by Tetra Tech (1978). Natural bypass of the harbor is shown by the 3- and 6-ft isopachs that extend from updrift around the eastern side of the north

breakwater. An accretionary lobe of natural bypass extends downdrift similar to that downdrift of Waukegan Harbor, but the Great Lakes natural bypass covers less areal extent and is thinner.

3.16 Erosion dominated the inner nearshore downdrift of Great Lakes Harbor. This erosion was also documented by Tetra Tech (1978). This area showed the worst nearshore erosion in the entire study area during this 64-year period. A broad area had nearshore erosion in the range 6 to 9 ft.

3.17 ***Lake Bluff to Highland Park (Figs. 3.2 and 3.3):*** Beginning in southern Lake Bluff and continuing southward, the accretion and erosion maps use a supplemental 1-ft contour interval because the nearshore changes are more subtle than those occurring from Waukegan Harbor southward to Lake Bluff.

3.18 Between Lake Bluff and Highland Park, the dominant nearshore change was erosion, also documented by Tetra Tech (1978, 1979). The maximum recorded erosion was 3 to 4 ft which occurred in several patchy areas along the Lake Forest shore at the present site of Forest Park Beach and along southern Lake Forest and Fort Sheridan. Approximately 2,000 feet lakeward of this zone of erosion, Tetra Tech (1978) indicates net accretion of as much as 8 feet.

3.19 ***Highland Park to Wilmette Harbor (Figs. 3.3, 3.4, and 3.5):*** Along the Highland Park nearshore, generally corresponding to the location of the Highland Park waterworks, a change began in the along-shore pattern of erosion and accretion. North of Highland Park, erosion dominated the nearshore, but beginning at the Highland Park waterworks a more patchy distribution of both erosion and accretion occurred. This patchy distribution was also documented by Tetra Tech (1979). Progressing southward from the waterworks, there was a trend towards increasing total area of accretion. Accretion dominated the nearshore along Winnetka, Kenilworth, and Wilmette as shown on Figure 3.5. Because of the timing and coverage of the U.S. Lake Survey maps, the map distribution of this figure has a base year of 1909 along northern Winnetka, and 1872 for central Winnetka to Wilmette Harbor. Thus the map coverage in this area is showing changes over a longer duration compared to the map coverages to the north (Figs. 3.1 through 3.4).

3.20 Maximum accretion updrift of Wilmette Harbor was slightly more than 6 ft, and a localized occurrence of slightly more than 9 ft is documented off Langdon Park. Natural bypass of Wilmette Harbor is documented by 3- and 6-ft isopachs of accretion on the downdrift side of the harbor. Unlike the natural bypass at Waukegan and Great Lakes Harbors, the natural bypass at Wilmette Harbor extended landward to intercept the shoreline. Tetra Tech (1980) noted substantial accretion lakeward of 20 feet LWD due to the deflection of the littoral stream.

3.21 Besides the accretion in the Wilmette Harbor vicinity, another area of marked accretion occurred along the Winnetka nearshore in the vicinity of Winnetka waterworks at Tower Road (Fig. 3.5), an area of significant accretion documented by Tetra Tech (1979). The majority of the accretion occurred updrift of the waterworks, but the accretionary area also extended downdrift. Most of the accretion was in the range 3 to 6 ft; localized occurrences of slightly more than 6 ft occurred opposite the waterworks.

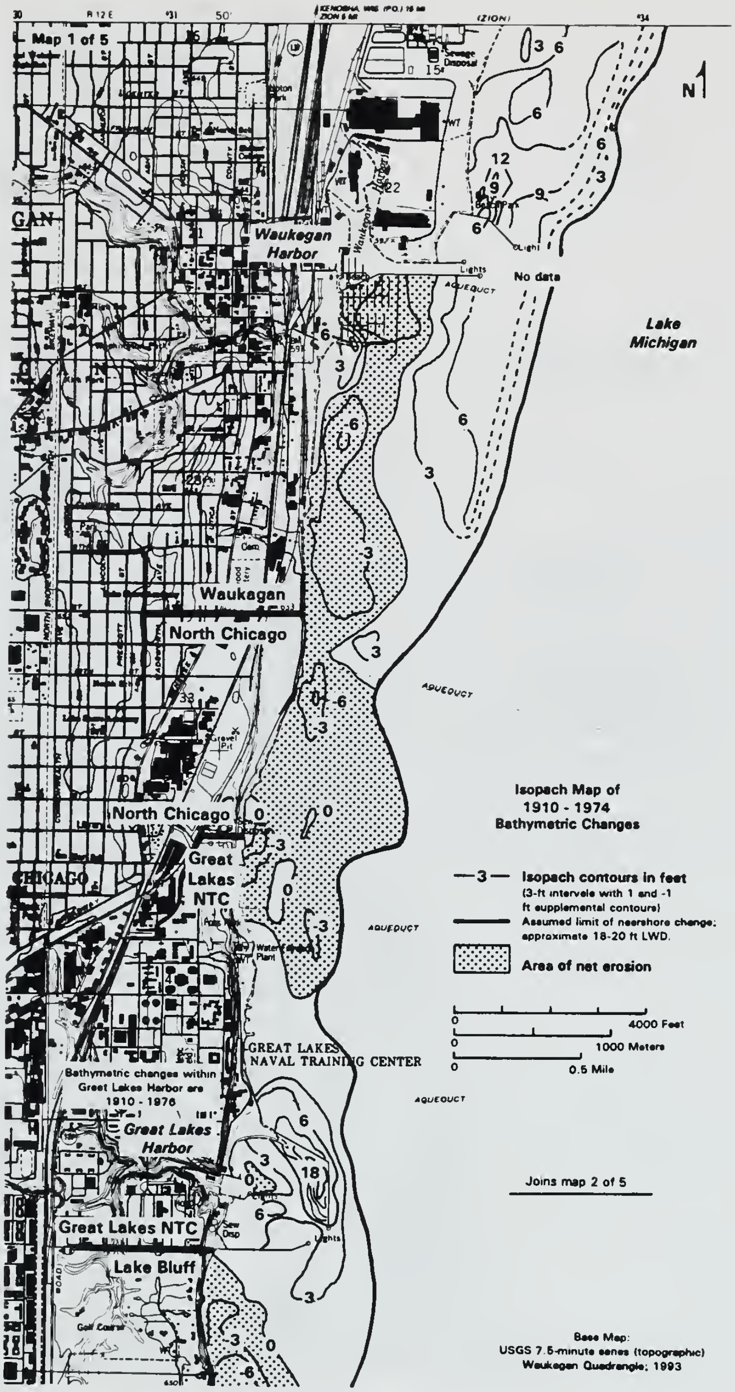

Figure 3.1. Isopach map of 1910-1974 nearshore erosion and accretion from updrift of Waukegan Harbor to Great Lakes Harbor (Map 1 of 5).

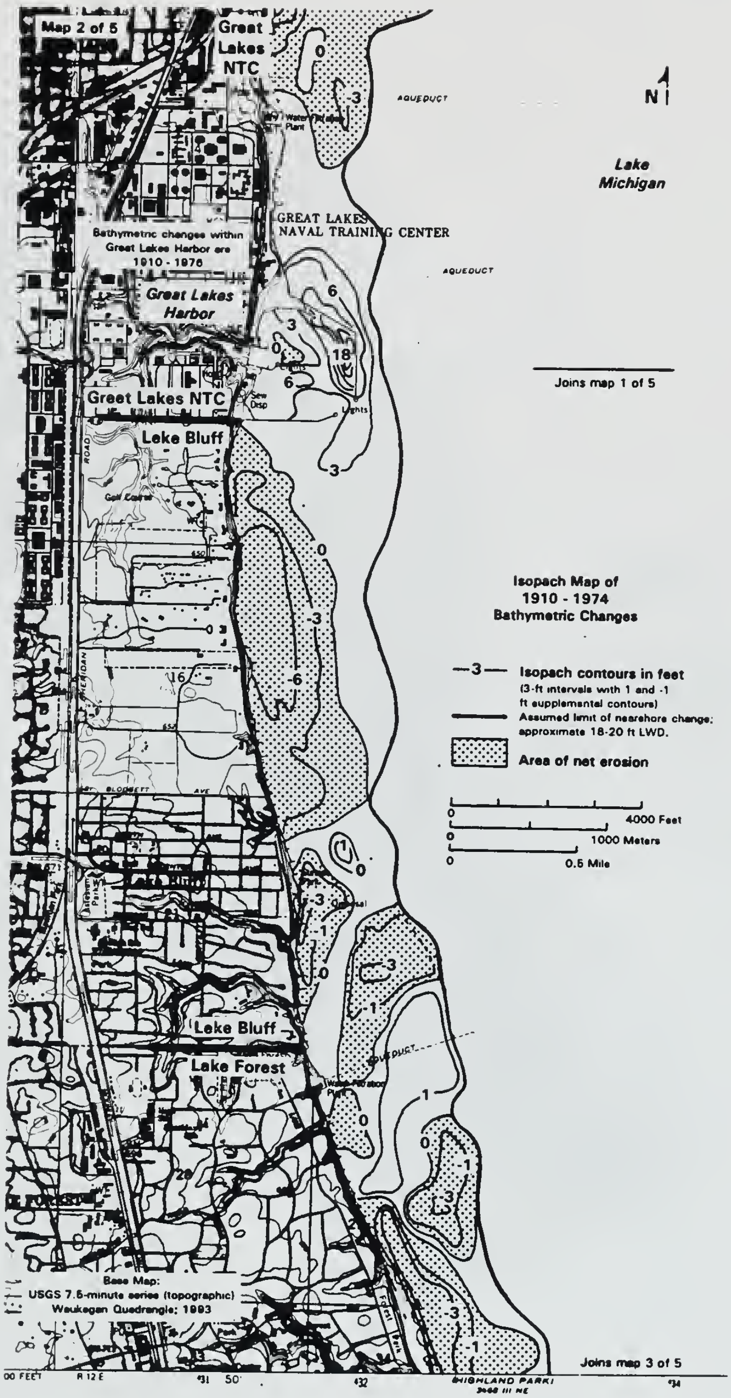

Figure 3.2. Isopach map of 1910-1974 nearshore erosion and accretion from Great Lakes Harbor to Lake Forest (Map 2 of 5).

Figure 3.3. Isopach map of 1910-1974 nearshore erosion and accretion from Lake Forest to Highland Park (Map 3 of 5).

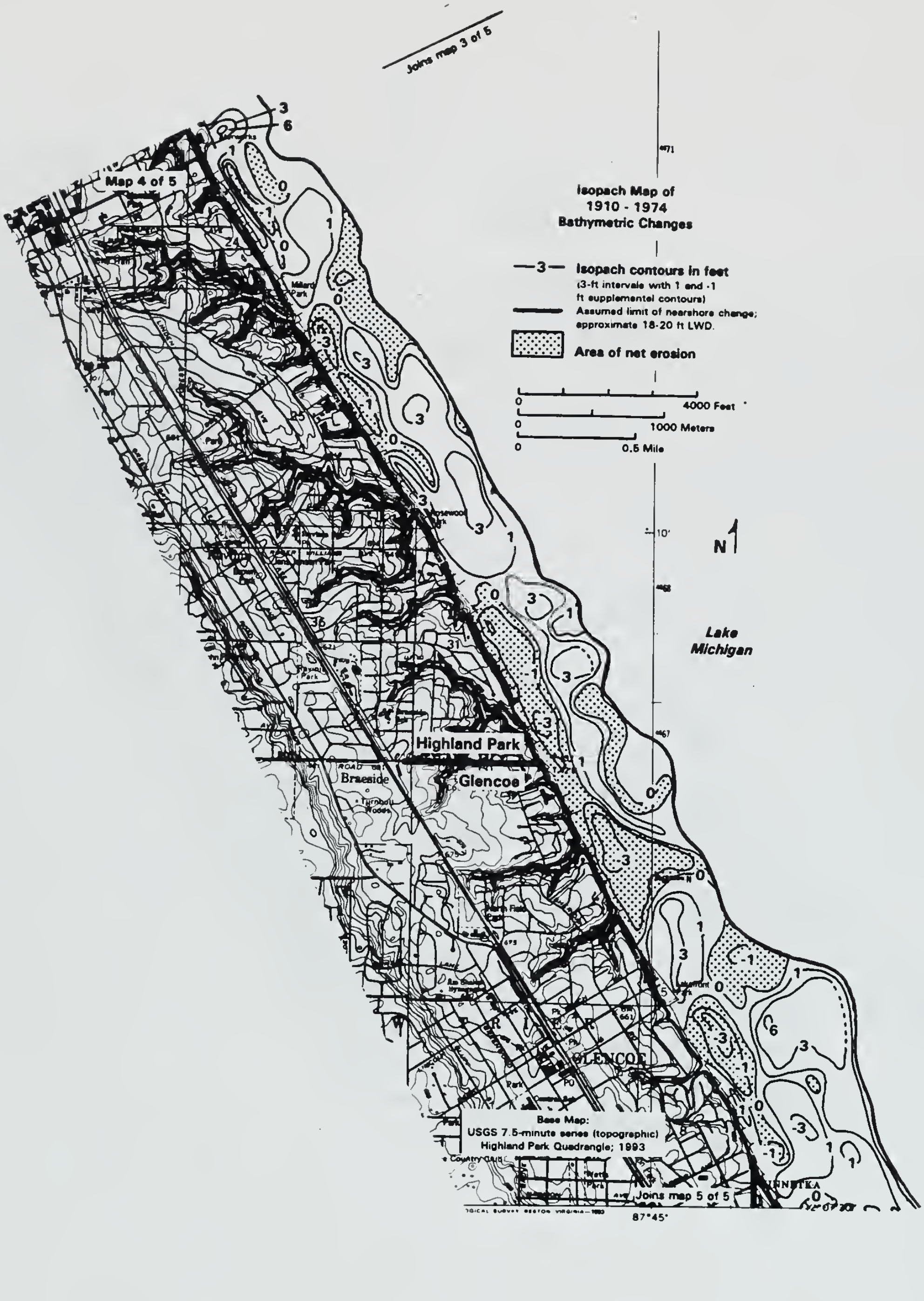

Figure 3.4. Isopach map of 1910-1974 nearshore erosion and accretion from Highland Park to Glencoe (Map 4 of 5).

Figure 3.5. Isopach map of 1909-1974 and 1872-1974 nearshore erosion and accretion from Glencoe to Wilmette Harbor (Map 5 of 5).

Nearshore Erosion and Accretion Volumes 1910-1974

3.22 The volumes of erosion and accretion were calculated by measuring the isopach areas and multiplying by the mid-contour values. The volume calculations were done for the entire nearshore from the south jetty at Waukegan Harbor to just south of the jetties at Wilmette Harbor (limit of mapping shown on Figure 3.5). The volumes were also computed within the nearshore limits of the different municipalities and government reservations. Corporate boundaries were extended offshore from the upland orientation, or if necessary, projected offshore perpendicular to the shoreline.

3.23 For the study area, the total 1910-1974 erosion is 8.4 million cu yds; the total accretion equals 11.6 million cu yds (Table 3.1). Thus the nearshore during this time experienced a net accretion of 3.2 million cu yds. The possible inputs of sediment were limited natural bypass at Waukegan Harbor, and bluff and beach erosion in the study area. No artificial bypass was occurring at Waukegan Harbor.

3.24 Table 3.1 shows the 1910-1974 nearshore volumetric changes computed for each municipality and the two U.S. Government properties. The far right column of Table 3.1 has the net volume change annualized and normalized per foot of shoreline. When arranged in geographic order from north to south, there is a general trend of updrift erosion and downdrift accretion. At Waukegan the net change was accretion, but this was primarily due to the natural bypass that occurred at Waukegan Harbor (Fig. 3.3). The volume estimate for the accretionary lobe representing the natural bypass shown on Figure 3.3 is about 1.6 million cu yds, which is nearly all of the nearshore accretion computed for the Waukegan nearshore (Table 3.1). Severe erosion occurred closer to shore. If the accretion volume of the natural bypass is ignored, then the Waukegan nearshore (south of the harbor) experienced a net erosion of 2.6 cu yds/ft/yr which was the most severe rate in the study area. Severe erosion also occurred along the nearshore of North Chicago. Both the Waukegan and North Chicago nearshore erosion can be attributed to littoral sediment starvation caused by Waukegan Harbor. Severe erosion occurred along the Lake Bluff nearshore which is downdrift from Great Lakes Harbor. Along the Highland Park shoreline a transition occurred from net erosion to net accretion. Net accretion increased southward to a maximum at Wilmette.

3.25 The harbor at Great Lakes Naval Training Center was the primary place of littoral sediment entrapment. Within the boundaries set by the base limits, the nearshore was dominated by accretion and the volume per shoreline foot per year exceeded that at Wilmette.

Table 3.1. Volume estimates of nearshore erosion and accretion for the period 1910-1974 for the municipalities and government installations of the study area. Area bounded by 0 feet LWD on the landward side and 18-20 feet LWD on the lakeward side. Erosion and accretion volume estimates rounded to the nearest hundred.

Municipalities and U.S. Government Installations (geographic order north to south)	Nearshore Erosion (cubic yards)	Nearshore Accretion (cubic yards)	Net Volume Change (E) designates erosion (cubic yards)	Shoreline Distance (feet)	Net Volume Change (per ft/yr) (E) designates erosion (cu yds/ft/yr)
Waukegan[1]	1,135,200	1,650,500	515,300	6,900	1.2[2]
North Chicago	821,800	54,600	(E) 767,200	6,600	(E) 1.8
Great Lakes Naval Training Center[3]	123,800	1,797,800	1,674,000	7,700	3.4
Lake Bluff	2,535,900	903,200	(E) 1,632,700	13,400	(E) 1.9
Lake Forest	1,520,300	527,400	(E) 992,900	16,700	(E) 0.9
Fort Sheridan[4]	457,500	201,300	(E) 256,200	5,700	(E) 0.7
Highland Park	941,500	768,700	(E) 172,800	25,000	(E) 0.1
Glencoe	453,600	1,070,200	616,600	10,100	1.0
Winnetka[5]	355,800	1,996,900	1,641,100	14,460	1.6
Kenilworth[6]	57,400	246,000	188,600	2,900	0.6
Wilmette[6]	25,300	2,401,000	2,375,700	9,650	2.4
SUMMATION	8,428,100	11,617,600	3,189,500	119,110	

[1]Northern limit of measurements and calculations is the Waukegan Harbor south jetty.
[2]Ignoring the accretion due to natural bypass, the net change is erosion (E) equalling 2.6 cu yds/ft/yr.
[3]Bathymetric comparison is for 1910-1974 outside the harbor, and 1910-1976 inside the harbor.
[4]Bathymetric comparison is for 1910-1975.
[5]Bathymetric comparison is for 1872-1974 and 1909-1974; 1872 mapping was needed because local 1909 data did not include the nearshore.
[6]Bathymetric comparison is for 1872-1974; 1872 mapping was needed because local 1909 data did not include the nearshore; volume calculations for Wilmette are made southward of Wilmette Harbor to the municipal boundary of Wilmette and Evanston.

NEARSHORE EROSION AND ACCRETION (1974-1994)

Map Distribution of Nearshore Erosion and Accretion

3.26 Mapping of changes from 1974 to 1994 is limited to the reach from Waukegan Harbor to Forest Park Beach at Lake Forest, which was the extent of 1994 bathymetric data collection. Another limitation is that the 1994 data collection did not extend into the shallow nearshore because of restrictions caused by draft of the survey boat. Thus the comparison of the 1974 and 1994 bathymetric data does not include a zone that extends from the shoreline out to a maximum of about 600 ft lakeward of the shoreline. Figures 3.6 and 3.7 show the map distribution of erosion and accretion plotted on USGS 7.5-minute topographic maps. Erosional areas are highlighted with a stipple pattern. The following discussions point out significant map patterns.

3.27 ***Waukegan Harbor to Great Lakes Harbor (Fig. 3.6):*** Erosion dominated this reach, but three localized areas of accretion occurred. From north to south, these accretion areas are as follows. (1) Accretion of between 1 and 2 ft occurred downdrift of the jetties at Waukegan Harbor. This accretion can be attributed to natural bypass at the harbor entrance. (2) The primary accretion area is centered about 3000 ft south of the Waukegan Harbor small-boat basin. This is the nearshore disposal site for sediment dredged at Waukegan Harbor. Accretion up to 4 ft is documented. This area received dredge disposal in September and October 1994 (see Table 4.2), and the 1994 bathymetric survey was done in November; thus the localization of the accretion may in part be a result of the most recent dredge disposal not yet being dispersed. (3) Downdrift from the disposal site, several localized accretional areas are documented off the southern shore of North Chicago and in several patchy areas north of Great Lakes Harbor. The lack of an accretionary lobe extending downdrift from the dredge disposal site indicates that (a) dredge spoil that is transported downdrift is moved rapidly across the nearshore with no prolonged residence time along the transport pathway, (b) an accretionary lobe that may customarily be present on the downdrift side of the disposal site was removed by a storm that occurred before the 1994 bathymetric survey, or (c) the dredge spoil is moved in pulses that the bathymetric comparisons cannot identify. Any one or all three of these factors may operate here.

3.28 Other than the localized accretion areas mentioned, the lake bottom is erosional and this erosion is essentially continuous from the south jetty at Waukegan Harbor to the north breakwater at Great Lakes Harbor. Erosion was generally 1 to 2 ft; localized erosion pockets of 3 to 4 ft occur, and several small areas are in the range 4 to 5 ft.

3.29 ***Great Lakes Harbor to Forest Park Beach (Fig. 3.7):*** Erosion dominated this reach. The most severe erosion is 5 to 6 ft off the southern Lake Bluff shoreline from Sunrise Park south to the Lake Bluff-Lake Forest boundary. Thus in this 20-year interval, this nearshore reach downdrift of Great Lakes Harbor experienced more severe erosion than the reach downdrift of Waukegan Harbor. An accretional area occurred east of the Great Lakes Harbor north breakwater. Here maximum accretion was in the range 2 to 3 ft. Accretion up to about 1 ft also occurred on the south side of the entrance to the harbor. The patterns of accretion around the eastern and southern sides of the harbor are consistent with natural bypass occurring as was the case prior to 1974.

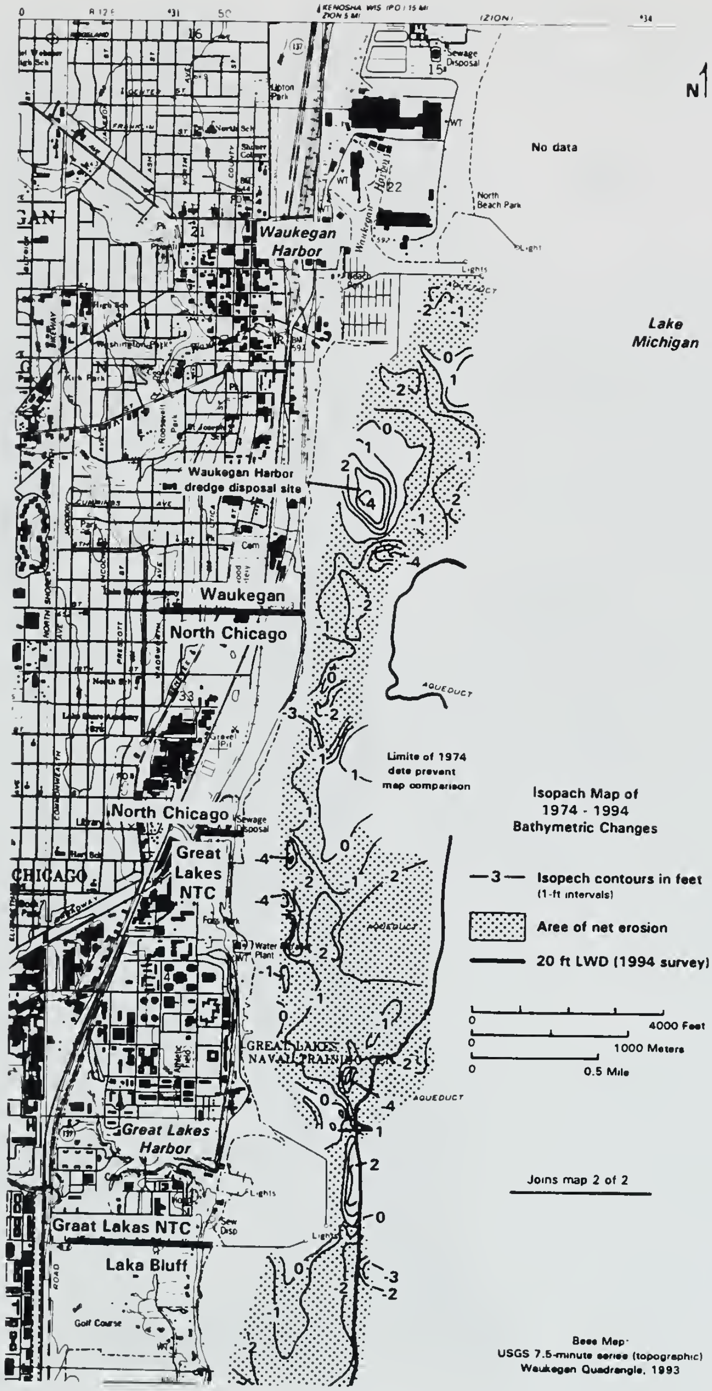

Figure 3.6. Isopach map of 1974-1994 nearshore erosion and accretion from updrift of Waukegan Harbor to Great Lakes Harbor (Map 1 of 2).

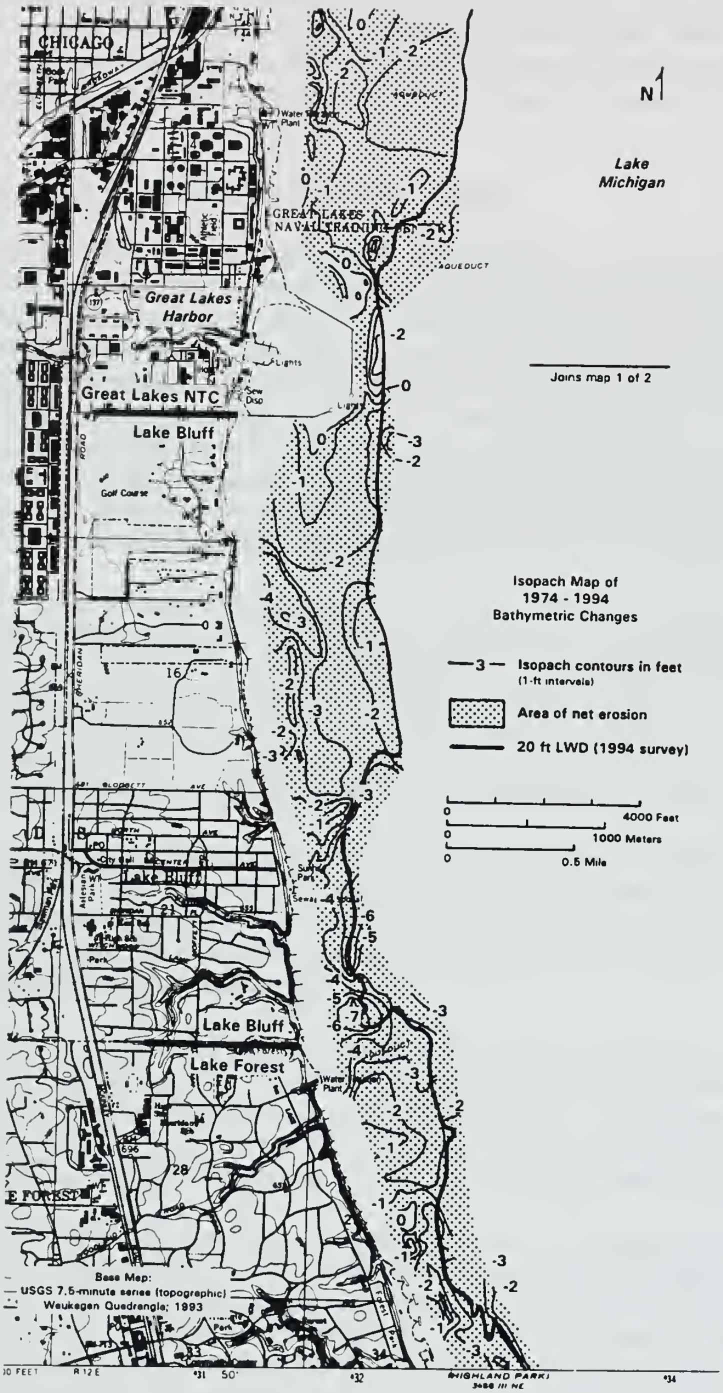

Figure 3.7. Isopach map of 1974-1994 nearshore erosion and accretion from Great Lakes Harbor to Lake Forest (Map 2 of 2).

3.30 The lakeward perimeter of Forest Park Beach has been an accretional zone since this facility was constructed in 1986 and 1987 (Trask and Chrzastowski, 1995). The isopach map does not show the accretion because the accretionary wedge is a narrow band close to shore and landward of the mapping limit. The accretion at Forest Park Beach is further discussed in Section 6 of this report.

Nearshore Erosion and Accretion Volumes 1974 - 1994

3.31 The volumes of erosion and accretion for lake-bottom changes from 1974 to 1994 were computed using the same methodology that was applied to the 1910-1974 comparisons (section 3.22-3.25). However, the 1974-1994 calculations could only be done as far as Forest Park Beach in Lake Forest which was the southern limit of 1994 mapping. In addition, the 1974-1994 volume calculations do not include the shallow nearshore within about 600 ft of the shoreline. This area was not covered in the 1994 data collection. For nearly all of the reach from Waukegan Harbor to Forest Park Beach, available profile data from 1991 (Shabica and Pranschke, 1994) indicate that erosion dominated between 1974 and 1991 in this shallow nearshore zone. This erosional trend likely continued into 1994. Thus the erosion volumes calculated are minimum estimates that would be exceeded if this additional area were included.

3.32 Table 3.2 shows the volumetric changes computed for the four municipalities within this reach plus the Naval Training Center. Net erosion dominated along each municipality and along the Naval Training Center outside of Great Lakes Harbor. Per foot of shoreline, the most severe average annual erosion occurred at Lake Bluff (8.8 cu yds/ft/yr). Waukegan had the least net erosion. This could be attributed to erosion being offset by the accretion resulting primarily from the artificial and natural bypass of Waukegan Harbor. Net erosion along the nearshore at North Chicago was greater than that at Waukegan by a factor of 9.5.

3.33 Comparison of data in Tables 3.1 and 3.2 provide a means of determining how trends and rates of erosion and accretion have changed in the past 20 years (1974-1994) compared to the previous 64 years (1910-1974). In making such a comparison, it is important to note that the 1974-1994 data are minimum erosion estimates since the shallow nearshore is not included as previously discussed (Section 3.42).

3.34 A similarity in both time intervals is that Lake Bluff experienced the most severe nearshore erosion. On an average annual basis, the erosion became more severe in the 20 years after 1974 compared to the 65 years prior to 1974. The change was from 1.9 cu yds/yr/ft in 1910-1974 to 8.8 cu yds/ft/yr in 1974-1994; an increase by a factor of 4.6. Increases in nearshore net erosion also occurred at North Chicago and at Lake Forest.

3.35 A reversal in net lake-bottom change occurred at both Waukegan and Great Lakes Naval Training Center. In both localities net accretion dominated in the interval 1910-1974. At Waukegan this 1910-1974 net accretion was primarily due to the accretional lobe resulting from the natural bypass of Waukegan Harbor (Fig. 3.1); at Great Lakes Naval Training Center the 1910-1974 net accretion was due to the entrapment within and marginal to Great Lakes Harbor. Subsequent to 1974, in both localities, former net accretional areas were eroding. This was despite the input of sediment from the artificial bypass of Waukegan Harbor.

Table 3.2. Minimum volume estimates of nearshore erosion and accretion for the period 1974-1994 for the municipalities and U.S. Naval base between Waukegan Harbor and Forest Park Beach at Lake Forest. Erosion and accretion volume estimates rounded to the nearest hundred.

Municipalities and U.S. Government Installations (geographic order north to south)	Nearshore Erosion (cubic yards)[4]	Nearshore Accretion (cubic yards)[4]	Net Volume Change (E) designates erosion (cubic yards)	Shoreline Distance (feet)	Net Volume Change (per ft/yr) (E) designates erosion (cu yds/ft/yr)
Waukegan[1]	301,600	216,300	(E) 85,300	6,900	(E) 0.6
North Chicago	790,100	34,900	(E) 755,200	6,600	(E) 5.7
Great Lakes Naval Training Center[2]	460,200	228,000	(E) 232,200	7,700	(E) 1.5
Lake Bluff	2,373,600	5,100	(E) 2,368,500	13,400	(E) 8.8
Lake Forest[3]	905,300	3,000	(E) 902,300	7,650	(E) 5.9

[1]Northern limit of measurements and calculations is the Waukegan Harbor south jetty.
[2]Erosion and accretion values include changes inside Great Lakes Harbor. Average annual erosion and accretion rates were used and multiplied by 20 years. The average annual rates are based on comparison of harbor bathymetric data collected in 1976 and 1992 (Fig. 5.6 this report).
[3]Coverage extends from border with Lake Bluff to southern part of Forest Park Beach (lat. 42°15′ N). Accretion on lakeward perimeter of Forest Park Beach is not included since 1994 data collection did not extend far enough landward.
[4]Erosion and accretion volume calculations do not include shallow nearshore within about 600 feet of shoreline since this zone is not covered in 1994 bathymetric survey.

OVERALL EROSION AND ACCRETION TRENDS 1910 TO 1994
WAUKEGAN HARBOR TO LAKE FOREST

General Statement

3.35 Comparison of the isopach maps for the interval 1910-1974 and the interval 1974-1994 provides a means of evaluating the nearshore trends for most of the 20th century. This analysis is limited to the nearshore from Waukegan Harbor to Forest Park Beach, which was the southern limit of the 1994 bathymetric survey.

3.36 The isopach map comparison documents that nearshore erosion was dominant from 1910 to 1974, and that nearshore erosion became even more widespread from 1974 to 1994. Additionally, areas that had been accretional in the first interval became erosional in the second, even though artificial bypass of dredge material from Waukegan Harbor to the nearshore south of the harbor first occurred in 1977.

3.37 This increase in nearshore erosion subsequent to 1974 is interpreted as the response of the nearshore to a deficit of littoral sediment supply. Although the nearshore was being supplied with artificial bypass from dredging at Waukegan Harbor, this input was apparently insufficient to counteract a negative sediment budget.

Waukegan Harbor to Great Lakes Harbor

3.38 From 1910 to 1974 there was natural bypass of Waukegan Harbor resulting in an accretionary lobe extending southward from the south jetty. Natural bypass was also occurring from 1974 to 1994, but during this time most of the former area of bypass accretion was being eroded. From 1910 to 1974, nearshore accretion was occurring updrift of Great Lakes Harbor from the north breakwater northward to Foss Park. Across this same area, however, in the interval 1974 to 1994, this former accretion area was being eroded along its more lakeward part. This net erosion apparently was a response to a deficit of littoral sediment supply that occurred subsequent to 1974. The sediment contribution from artificial bypass of Waukegan Harbor was less than what was needed to prevent this net erosion.

Great Lakes Harbor to Forest Park Beach

3.39 From 1910 to 1974 there was natural bypass of Great Lakes Harbor resulting in an accretionary lobe extending southward from the south breakwater. Nearly all of this former accretionary area was erosional in the interval 1974 to 1994. Maximum erosion here was in the range 2 to 3 ft. Closer to shore, severe erosion is shown prior to 1974. According to Norby (1981), by 1976 most nearshore sand had been stripped from this area. The severe erosion that persisted from 1974 to 1994 therefore indicates downcutting of the glacial till generally in the range of 2 to 4 ft, but with at least one localized occurrence exceeding 5 ft.

3.40 The lobate area of severe nearshore erosion in the interval 1910 to 1974 had its southern limit at about Sunrise Park, which is about 1.9 miles south of the south breakwater at Great Lakes Harbor. The 1974 to 1994 comparison indicates that the most severe erosion occurred from Sunrise Park southward to the Lake Bluff-Lake Forest boundary where maximum erosion locally exceeded 7 ft. This indicates a downdrift advance of this severe erosional area.

OVERALL EROSION AND ACCRETION TRENDS 1974 TO 1994
LAKE FOREST TO WILMETTE HARBOR

3.41 Lack of regional bathymetric data subsequent to 1974 prevents nearshore mapping and evaluation of changes from Lake Forest to Wilmette Harbor. However, generalizations of post-1974 trends can be made based on limited coverage of sidescan-sonar mapping done in 1994 for the Interim IV study by the USGS (Foster *et al.*, 1995), and profile and probing data conducted by Shabica *et al.* (1991) and Shabica and Pranschke (1994).

3.42 Prior to 1974, the southern limit of till exposures in the nearshore was generally along the Lake Forest shore (Collinson *et al.*, 1979). The 1994 sidescan-sonar mapping indicates that this area of nearshore sand removal has expanded southward to the Glencoe shore.

3.43 Profile comparisons and sand probing indicate that for the transects examined between Fort Sheridan and Wilmette Harbor between 1974 and 1990, the net change was erosional in nearly all cases. The erosional trends were even indicated by profile comparisons along Gillson Park at Wilmette, which is the area of thickest and most extensive beach and nearshore sand in the study area.

NEARSHORE EROSION RATES

General Statement

3.44 A detailed analysis of nearshore erosion rates in the Interim IV area was not done for this study. These rates are likely quite variable temporally and spatially. Some generalizations concerning nearshore erosion rates can be made based on previously published data and profile comparisons done for this study.

Sand Erosion Rates

3.45 Shabica *et al.* (1991) and Shabica and Pranschke (1994) compared 1975 and 1989-1990 profile data from the southern, sand-dominated nearshore area of this study in Highland Park, Kenilworth, and Winnetka. All erosion occurred within the sand layer. Average rates of erosion ranged from a maximum of about 0.28 ft/yr at Winnetka to a minimum of 0.16 ft/yr at Kenilworth.

Till Erosion Rates

3.46 Bathymetric comparisons in areas of known nearshore exposure of till provide a means of calculating till downcutting rates. The most widespread and persistent nearshore exposure of till occurs at Lake Bluff. This locality is crossed by Profile 12 established by Shabica and Pranschke (1994). Figure 3.8 shows profile changes along this line for 1910, 1974, 1991, and 1994. The 1991 data were collected by Shabica and Pranschke (1994); other profiles are derived from other bathymetric surveys and have been plotted along this line. Based on sidescan-sonar mapping (Foster *et al.*, 1995) and probing (Shabica and Pranschke, 1994) this profile crosses exposed till in all but the most landward and lakeward parts of the profile.

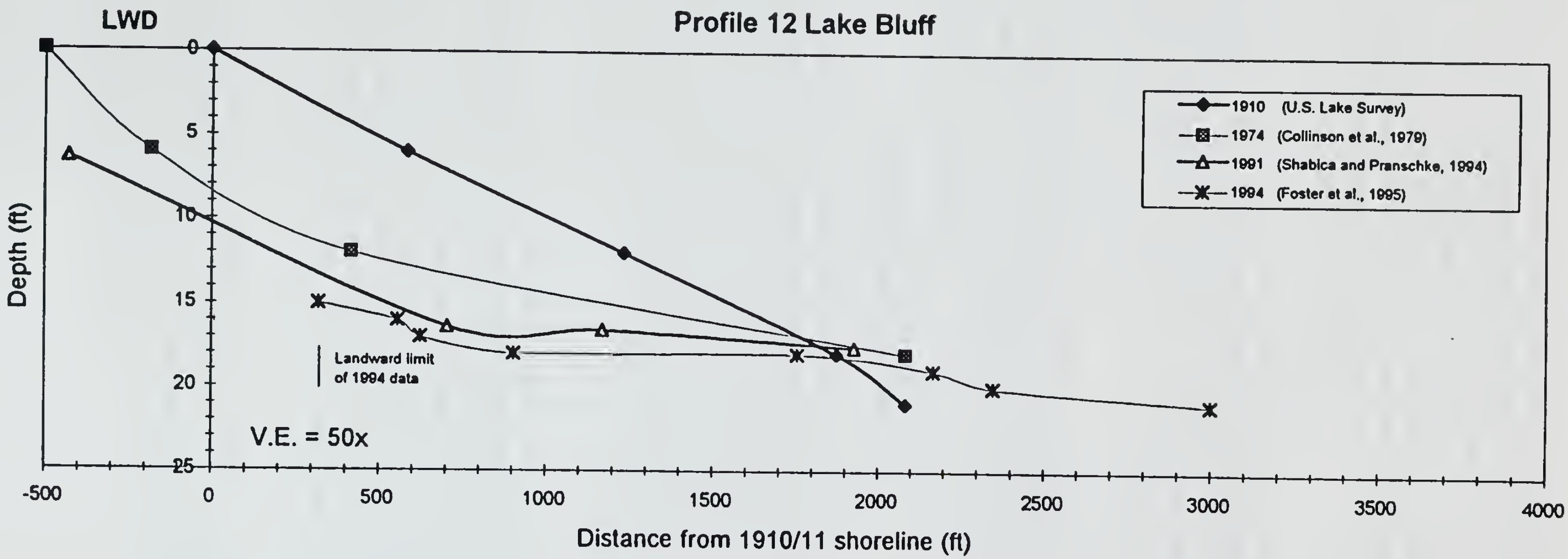

Figure 3.8. Nearshore profile comparisons along Profile 12 of Shabica and Pranschke (1994) at Lake Bluff.

3.47 Between 1974 and 1991, the most severe till downcutting along Profile 12 occurred at depths of 13 to 17 ft LWD. The downcutting totaled 3.2 ft giving an average annual rate of 0.19 ft/yr. Between 1991 and 1994, additional till downcutting occurred. The maximum amount was 1.5 ft which is an average annual rate of 0.5 ft/yr. However, caution may be needed in accepting this rate; the symmetry of the 1991 and 1994 profiles raises some uncertainty about vertical registration of the data. Elsewhere in the area of nearshore erosion at Lake Bluff, the 1974-1994 bathymetric comparisons (Fig. 3.7) indicate maximum erosion of at least 5 ft which is an average annual rate of 0.27 ft/yr.

3.48 These rates of 0.19 ft/yr and 0.27 ft/yr are in fairly close agreement with the rate of till downcutting that Foster *et al.* (1992) determined for the lake bottom downdrift of the harbor structures at St. Joseph, Michigan. Based on comparison of 45 years of bathymetric data, the rate determined was 0.29 ft/yr. No significant differences occur in the characteristics of the till at Lake Bluff, Illinois and St. Joseph, Michigan. The Wadsworth Till member of the Wedron Formation occurs at both localities.

3.49 The 1974-1994 bathymetric comparison indicates that even higher rates of till erosion possibly occur in one locality in the nearshore of southern Lake Bluff. As much as 6 and 7 ft of erosion are documented (Fig. 3.7). In 1974, this area of lake bottom had a veneer of fine sand or silt over till. Thus most of the 1974-1994 erosion occurred in till. The 6-7 ft erosion gives average annual rates of 0.30-0.35 ft/yr.

PROFILE COMPARISONS

3.50 The profile for the Lake Bluff nearshore shown in Figure 3.8 documents the worst case in the study area of nearshore downcutting and steepening of the slope across the shallow nearshore. The armored shoreline essentially remained stationary from 1974 to 1991, thus an extrapolation is possible for the 1991 data from 0 ft LWD to the first recorded 1991 data point at 6.5 ft LWD. Using this extrapolated line, between 1910 and 1991, the slope from 0 to 5 ft LWD steepened by 882 percent; the slope from 0 to 10 ft LWD steepened by 118 percent (also see Attachment 4, Profile 12). The trends documented in this Lake Bluff profile are an example of the nearshore erosion that could occur with time along all the nearshore erosional zones from Waukegan to Wilmette.

3.51 An attachment to this report is a collection of profile comparisons for eight localities in the study area. The profile locations are those used by Shabica *et al.* (1991) and Shabica and Pranschke (1994). In all but two cases these are lines first established by Collinson *et al.* (1979) and reoccupied by Shabica and Pranschke for comparison. The two exceptions are Profile 11 (North Chicago) and Profile 12 (Lake Bluff). Data for other survey years have been obtained from bathymetric surveys and plotted along these lines of profile. In all of the profiles, care is needed in interpreting the profile shapes for the data from 1872 and 1910 because the total number of control points is limited, and a smoothed line is assumed between the control points.

3.52 Also included in the attachments are tables that summarize measurements made from each of the eight profile comparisons. For the different survey years, the tables provide measurements of: 1) vertical and horizontal profile changes occurring at different depths; 2) depth measurements at 100-ft distances offshore (100-500 ft); and 3) slope calculations across the shallow nearshore (0-5, 5-10, and 0-10 ft).

SECTION 4 COASTAL IMPACTS AT WAUKEGAN HARBOR

HARBOR DESCRIPTION

4.1 Waukegan Harbor is the northernmost of the three Corps of Engineers harbor facilities on the Illinois coast of Lake Michigan. The other two are Chicago Harbor on the central Chicago lakefront, and Calumet Harbor which straddles the Illinois-Indiana state line. Waukegan Harbor is significantly different from these other two harbors in that: 1) it is not associated with a river mouth; 2) it is the smallest of the three in total area; and 3) unlike either Chicago Harbor or Calumet Harbor where littoral transport volumes are minimal, at Waukegan Harbor dredging is required to maintain project depths through the harbor-entrance channel.

4.2 The jetties at Waukegan Harbor, called North Pier and South Pier, have an east-west orientation, making them essentially coast-perpendicular (Fig. 4.1). A shore-attached breakwater located north of the channel entrance functions both to protect navigation from northerly waves at the harbor entrance, and to act as a partial barrier to the net southerly littoral transport that causes shoaling near the entrance.

4.3 The jetties, breakwaters, and bulkheads that define Waukegan Harbor have a variety of designs and construction materials. Bottin (1988, p. 157-158) shows cross sections of these structures. The majority of the construction consists of rock-filled timber cribs capped with reinforced concrete. All construction is typical of Corps of Engineers shore structures that were built in southern Lake Michigan in the late 1800s or early 1900s.

4.4 Within the last 10 to 15 years, the overall plan view of the Waukegan Harbor complex has been changed by two projects. First, along the shore south of South Pier, a recreational harbor was constructed with protection provided by two rubble-mound breakwaters. Second, in the innermost part of the harbor, former Slip No. 3 was filled and "sealed" to entomb a high concentration of PCBs resident in this slip. A new slip was constructed in the northeast corner of the inner harbor.

CONSTRUCTION HISTORY

4.5 The history of federal involvement in the planning, building, and maintenance of a commercial harbor at Waukegan spans more than 140 years, beginning in the mid-1800s and continuing to the present. The construction history is important in understanding how this facility has impacted local coastal changes and patterns of littoral sediment transport.

4.6 The construction and maintenance history is recorded in the Annual Reports of the U.S. Army Chief of Engineers beginning in the 1880s. The Waukegan Harbor history is divisible into an 1800s phase and a 1900s phase.

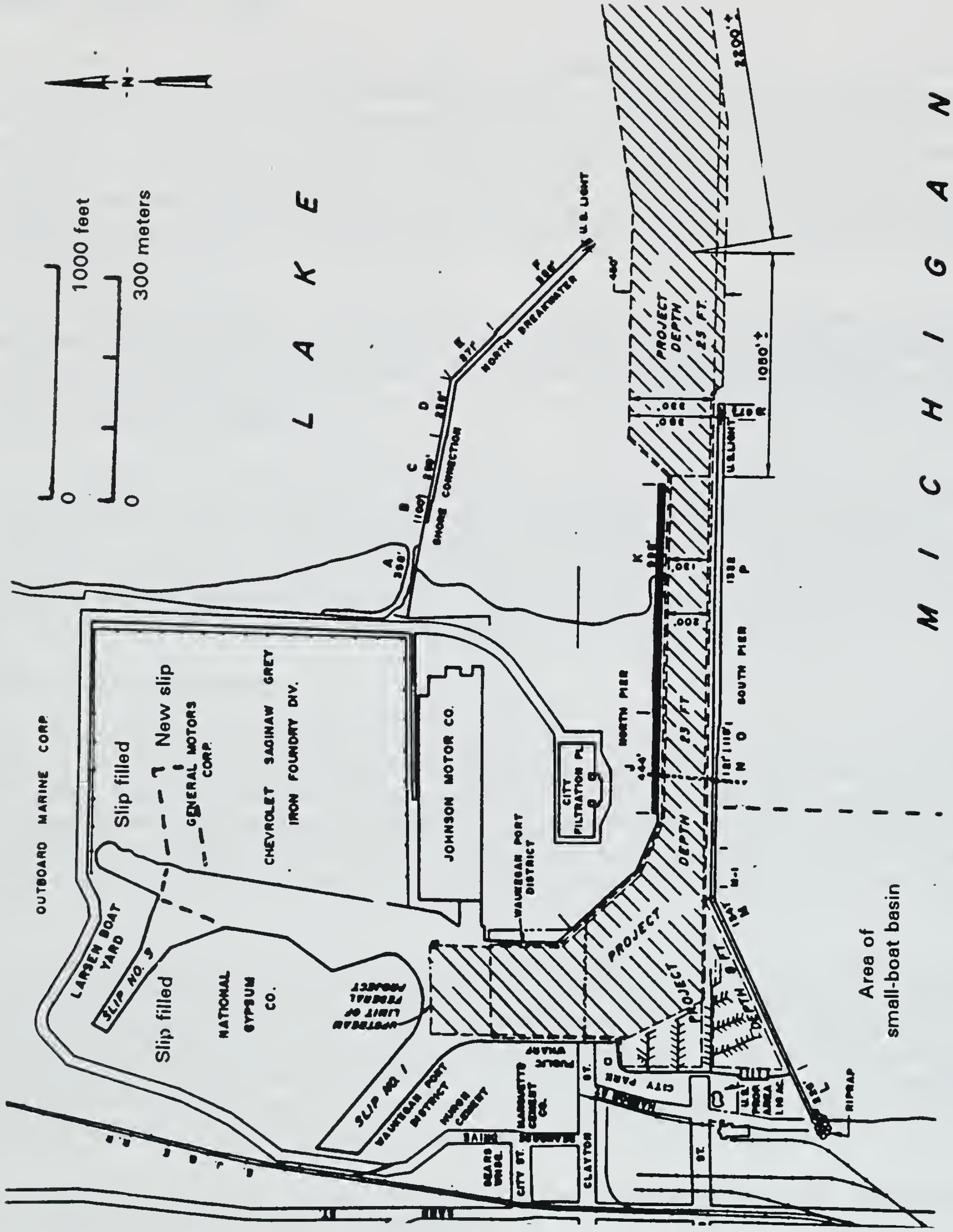

Figure 4.1. Plan of the Waukegan Harbor complex. Letters along the breakwater and jetties identify different structural designs. Project depths are in feet referenced to Low Water Datum. This map predates construction of the small-boat basin on the south side of South Pier and modification of slips in the inner harbor(modified from Bottin, 1988).

1800s Construction History

4.7 Federal involvement in building a harbor at Waukegan began in 1852. At that time no protection existed for commercial vessels at Waukegan. Two privately owned piers extended about 500 ft into the lake to a depth of about 12 ft. These were located south of the present-day harbor. The lack of any defense from the open lake restricted safe moorage to times of calm water. A federal appropriation of $15,000 in 1852 provided for the construction of an offshore, detached breakwater in 20 ft of water running parallel to the shore opposite the piers. One 30-ft-long section of rock-filled timber crib was built, but it was soon damaged and carried away in a storm, and work was abandoned.

4.8 The next occurrence of federal activity was 1873. A Corps of Engineers survey was made and a plan proposed for constructing a shore-parallel, offshore breakwater. No action was taken. A Corps survey was again made in 1879. In 1880 construction began on a pair of rock-filled timber cribs, referred to as North Pier and South Pier, initially intended to extend no more than 300 ft offshore.

4.9 Annual Reports of the Chief of Engineers, beginning in 1881 and continuing through 1895, describe the work progress, damage to the structures caused by waves and ice, and several stages of modifying the project as coastal processes of accretion and erosion caused engineering challenges. Figure 4.2 shows successive shoreline positions and length of the harbor structures between 1883 and 1889. Updrift accretion, harbor shoaling, and development of a bar across the harbor entrance were all continuing problems.

1900s Construction History

4.10 The present-day Waukegan Harbor results from construction in the 20th century, and all 1800s construction has essentially been eliminated by expansion and improvements to form the modern harbor. However, the construction in the 1800s established the location and orientation of the entrance channel, and set the stage for the angled nearshore segment of the south pier as the original structure deteriorated beyond reasonable state of repair. The inset map of Figure 4.2 shows the location and size of the harbor in 1889 relative to the modern harbor.

4.11 Two phases of construction occurred in building the modern harbor. The first phase occurred from 1902 to 1906. During this time the jetties were built to their present offshore extent. The angled nearshore segment of the south pier was part of this construction. The north breakwater was also constructed. This was initially built as an offshore (detached) breakwater. The second phase occurred from 1930 through 1932. During this time the major new construction was the shore connection to the north breakwater. Other work in this phase consisted of placing stone and concrete caps and superstructures on the jetties.

4.12 Since the 1930s, all work on the structures has been maintenance and rehabilitation. No extensions to the structures have occurred.

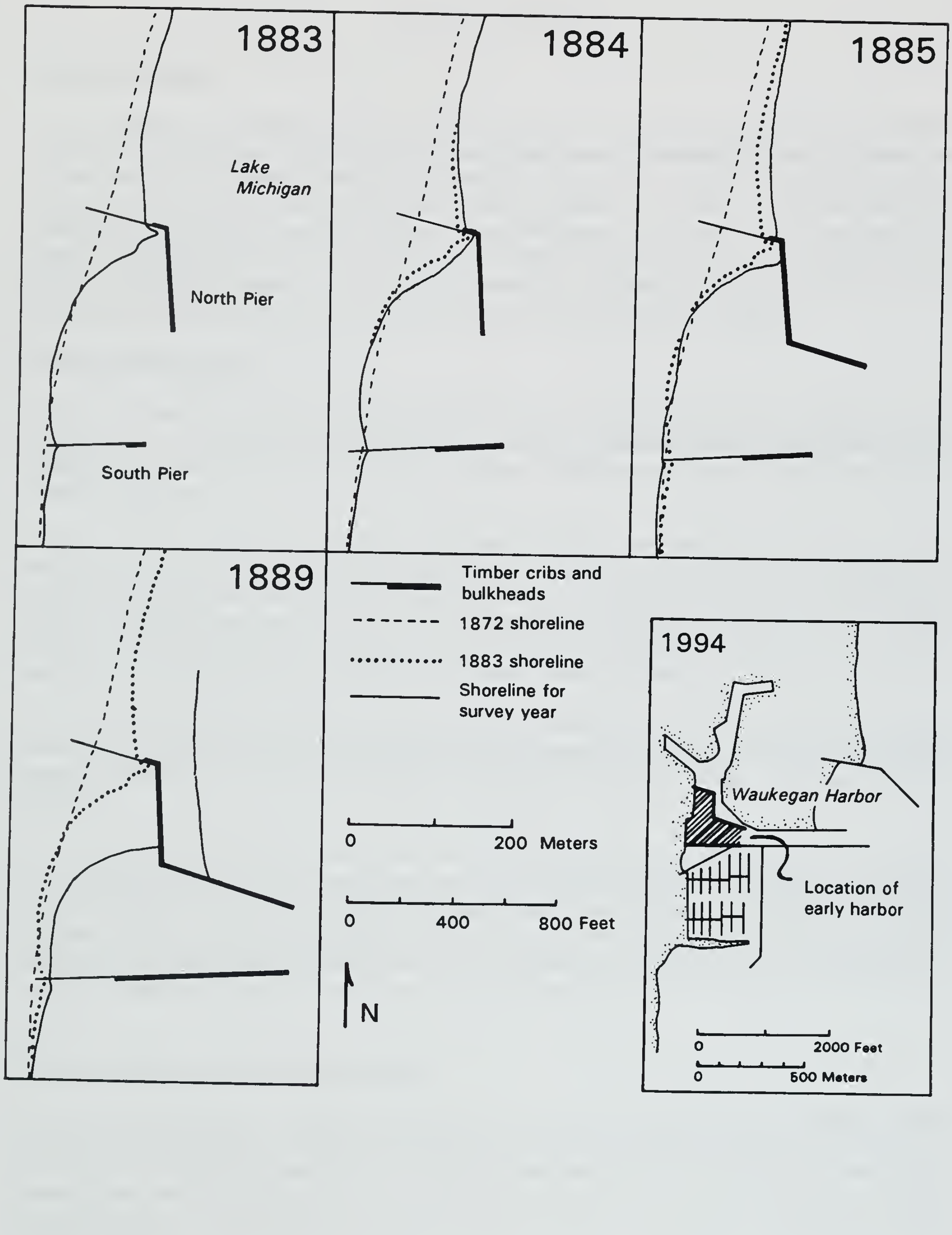

Figure 4.2. Maps showing successive stages in the construction of the early Waukegan Harbor and the associated shoreline changes (modified from U.S. Army Corps of Engineers Annual Reports 1882 through 1889).

DREDGING HISTORY

Dredging Overview

4.13 Dredging at Waukegan Harbor first occurred in 1889 and has been an intermittent maintenance requirement ever since. In general, maintenance dredging has occurred every one or two years. The primary dredging area has been the entrance channel between the jetties and the approach from lakeward of the jetties. During the 1960s, yearly dredging was necessary while the lake was in a phase of low lake levels that included the historical low in 1964. No dredging occurred from 1940 through 1947 which in part can be attributed to World War II. With the exception of several instances of dredging by the City of Waukegan, all dredging has been done through contracts initiated by the Corps of Engineers.

Dredging Data Sources

4.14 The records of the volume of sediment removed during dredging are included in the Annual Reports of the Chief of Engineers for work at Waukegan Harbor beginning with the 1889 report. Additional data since about 1920 are available in the files of the Chicago District Corps of Engineers.

4.15 Dredge volumes are typically recorded as either "Bin Measures" (B.M.) or "Scow Measures" (S.M.). These terms mean the same and are a measure of the volume filling the barge. These volumes include air and water as well as sediment. An alternate measure is "In Place" measurements, which are the volumes generated from post-dredging surveys and thus measure the actual volume of material removed. The bin (or scow) volumes are inflated by a factor of 10 to 20 percent in comparison to the in place volumes.

4.16 Most dredging at Waukegan Harbor has removed sand. However, in a few instances when the channel and harbor were initially being dredged to a new and deeper controlling depth, the dredging was deep enough to intercept the glacial till that underlies the sand deposits.

4.17 The Annual Reports mention that fine-grained sediments were dredged in some cases, but no distinction is made between volumes of sand and volumes of fine-grained sediments. The total volume of these finer sediments would be minor compared to the total volume of all dredging. Once the initial dredging was done to form a deeper channel into these finer-grained sediments, all subsequent dredging would be removal of entrapped sand. It is reasonable to use the dredge records solely as a record of sand removal.

History of Offshore (Deep-Water) Disposal

4.18 The early history of dredging at Waukegan Harbor involved disposal of sediment in deep water in Lake Michigan, at depths well beyond any transport likely to return sediment to the littoral zone. The Annual Reports do not specify a disposal site, but records from the Chicago District that begin in 1918 indicate the disposal area was 2.5 miles due east of the north breakwater light. It is assumed that dredging from 1889 to 1918 had a comparable offshore disposal area.

4.19 Table 4.1 summarizes the bin-measure volumes for all dredging with offshore disposal. The final year of offshore disposal was 1982. Thus the practice of offshore disposal spanned a total of 93 years (1889-1982). The volume of material dredged per dredge event is variable

due to several factors such as differences in time since the most recent dredging, area of dredging, recent lake-level history, depth of dredging, and fluctuations in littoral sediment supply.

4.20 The summation for all offshore disposal is 2,492,754 cu yds, or about 2.5 million cu yds. Using a factor of 15 percent to reduce this bin measure to an in-place measure, the in-place volume is 2,118,840 cu yds (2.1 million cu yds).

Table 4.1. Waukegan Harbor dredge records during history of offshore disposal of dredge spoil. All volumes are assumed to be bin measures.

Fiscal Year (July through June)	Dredge Volume (Cubic Yards)
1928	17,805
(1880 - 1889)	17,805
1890	63,069
1892	9,714
1893	50,292
1897	128,862
1898	58,249[1]
(1890 - 1899)	310,186
1900	33,650[2]
1928	26,722
1898	280,900
1909	5,004
1907	9,129
1909	6,426
1909	14,866
(1900 - 1909)	376,697
1900	53,453
1907	7,791
1913	10,220
1914	31,929
1915	31,163
1916	37,106
1917	19,600
1918	28,880[3]
1919	50,510
(1910 - 1919)	270,652
1920	16,837
1921	36,750[3]
1922	59,500[3]
1928	30,000[3]
1924	50,000[3]
1925	41,700[3]
1929	60,498[3]
1924	73,622
1928	77,359
1929	[4]
(1920 - 1929)	446,266
1930	111,485
1931	90,164
1933	28,500
1931	28,500
1936	18,746
1931	89,871
1939	23,917[5]
(1930 - 1939)	391,683
1948	56,041
(1940 - 1949)	56,041
1950	29,640
1958	108,200
(1950 - 1959)	137,840
1960	12,629
1961	39,900[6]
1963	47,191
1964	50,812
1965	41,279
1966	49,370[7]

Table 4.1. Waukegan Harbor dredge records during history of offshore disposal of dredge spoil. All volumes are assumed to be bin measures.

Fiscal Year (July through June)	Dredge Volume (Cubic Yards)	Fiscal Year (July through June)	Dredge Volume (Cubic Yards)
1967	32,491	1977[9]	[11]
1969	33,456	(1970 - 1979)	93,060
(1960-1969)	307,128	1982[9,12]	85,396
1974	~10,000[8]	(1980 - 1982)	85,396
1975	~48,369[8]	Summation	
1976[9]	34,691[10]	(1889 - 1982)	2,492,754

[1]City of Waukegan also doing dredging; volume not known/disposal area not known.
[2]Dredging by Western Coal and Dock Co.; reported in Annual Report of the Chief of Engineers for FY1900.
[3]Volume provided by files in Chicago District office; no volume given in Corps of Engineers Annual Report, although reports give cost of annual dredging.
[4]Corps of Engineers Annual Report notes that no dredging was necessary because of dredging by City of Waukegan to remove large volume of sand updrift of harbor, which sand was used at some unknown location for fill; removed volume unknown.
[5]Includes 18,177 cubic yards of maintenance dredging from inner basin.
[6]Volume from Annual Report; data from Chicago District records 52,972 cubic yards (bin measure) and 45,025 cubic yards (in-place measure).
[7]Volume from Annual Report is 40,224 cubic yards; data from Chicago District indicates this is in-place measure.
[8]Volume from data of Chicago District office; no volume given in Annual Report, but occurrence and cost of dredging is given; disposal was onshore adjacent to Inner Basin and therefore removed from littoral drift.
[9]Federal fiscal year October through September.
[10]Data from Chicago District office; Annual Report states volume "approximately 40,000 cubic yards" for FY1974 and FY1977.
[11]Annual report and data from Chicago District office record volume of 130,000 cu yds; Chicago District office records disposal as "just south of south pier;" thus disposal is considered bypass and not included here as offshore disposal.
[12] Last occurrence of offshore disposal.

History of Nearshore (Shallow-Water) Disposal

4.21 Disposal of dredged material into the nearshore zone south (downdrift) of the harbor eventually became the practice for managing the dredged sediment. This nearshore disposal established a means for artificial bypass of littoral sediment.

4.22 Downdrift disposal began in 1977. Corps records indicate that in that year sediment was dumped "just south of the south pier." In 1982, sediment was once again disposed of offshore. Beginning in 1984, and for all subsequent dredging through 1994, disposal has been in a designated disposal site located south of the entrance to the small-boat basin on the south side of Waukegan Harbor (Fig. 4.3). Water depth in this disposal area in 1974 was about 12-15 ft LWD. Since that time, depths have become shallower due to disposal of dredge spoil.

4.23 The summation of nearshore disposal from 1977 through 1994 is a bin volume of 578,647 cu yds (Table 4.2), or about 0.6 million cu yds. Using a factor of 15 percent to reduce this bin volume to an in-place volume, the in-place volume is 491,850 cu yds.

4.24 There is no record of any disposal along the beaches or nearshore zone to the north (updrift) of the harbor. Such updrift disposal is called "backpassing." Backpassing is a management procedure to return sand updrift of a barrier or place of entrapment.

Comparison of Offshore and Nearshore Disposal Volumes

4.25 As of 1994, the history of dredging and dredge disposal at Waukegan Harbor spans 105 years and primarily involves permanent removal of sediment from the littoral transport system. Bypassing has occurred for a little more than a decade. Table 4.3 compares the bin volumes and estimated in-place volumes for all offshore and nearshore disposal. The total volume of sand dumped offshore is 4.3 times greater than that placed in the nearshore.

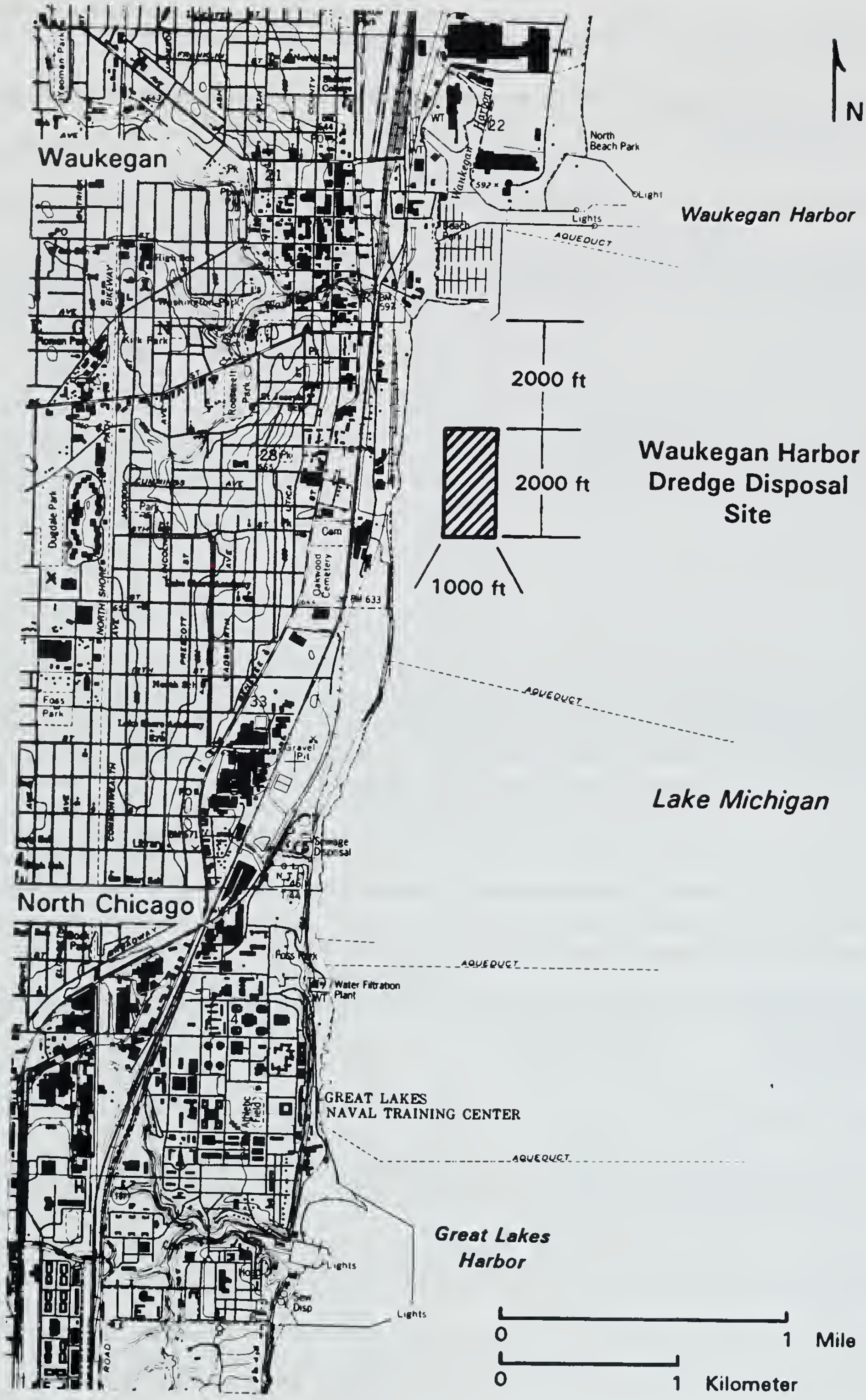

Figure 4.3. Location of nearshore disposal site for sediment dredged from Waukegan.

Table 4.2.	Waukegan Harbor dredge records during history of nearshore disposal of dredge spoil.		

Calendar Year	Month(s) of Dredging	Dredge Volume (Cubic Yards; Bin Measure)	Volume Summation for Decade (Cubic Yards)	
1977	Jun - Jul	130,000[1]	(1970 - 1979)	130,000
1984-1985	Aug - June	81,000[2]		
1985	Oct	26,180		
1985	---	100,996	(1980 - 1989)	208,176
1990	Jul - Nov	49,513		
199[illegible]	Sept	79,482		
1993	May - Jun	66,597		
1994	Sept - Oct	44,879	(1990 - 1994)	240,471
Summation			(1977 - 1994)	578,647

[1]Both Annual Report and data from Chicago District record dredge volume of 130,000; records from Chicago District indicate disposal area was "just south of south pier."
[2]Disposal in 1984 begins placement of dredge material in designated nearshore area south (downdrift) of harbor.

Table 4.3.	Summary of volumes for offshore and nearshore disposal of dredge spoil from Waukegan Harbor (1889-1994).		

	Bin Volumes (Cubic Yards)	In-Place Volumes[1] (Cubic Yards)	Percentage of Total Dredging
Offshore Disposal	2,492,754	2,118,841	81
Nearshore Disposal	578,647	491,850	19
Summation	3,071,401	2,610,691	100

[1]In-place volumes based on estimate of 15% of bin volume being attributed to air and water.

COASTAL EVOLUTION IF WAUKEGAN HARBOR HAD NOT BEEN BUILT

4.27 Considerable attention has been given to the volume of littoral sediment that has accreted on the north (updrift) side of the harbor jetties. This accretion has caused pronounced lakeward progradation of the shoreline since the late 1800s (Fig. 4.4). For example, measured on an east-west line just north of the north breakwater, the 1991 shoreline was about 2400 ft lakeward of the 1872 location. The question arises as to how this shoreline would have evolved _if_ Waukegan Harbor had not been constructed.

4.28 The geomorphology of the Zion beach-ridge plain provides a means to model how the plain would have migrated southward with time if the harbor had not been built. An assumption is made that the conditions of the recent geologic past would be maintained, such as amount of littoral sediment supply, long-term average lake level, and typical wave energies. Another assumption is that the lake-bottom morphology downdrift of the beach-ridge plain is similar to the ancient lake bottom that now lies beneath the plain. For calculation purposes, these areas are assumed to be comparable because if depths were different, different volumes of sediment would be needed for equivalent lateral translation of the shoreline. All of these assumptions are reasonable except for the maintenance of the littoral sediment supply. Human activity along the shore updrift from the harbor area could significantly influence the supply.

4.29 Figure 4.5 shows selected beach ridges in the southern part of the beach-ridge plain. Dates on these ridges, assigned by Collinson (1982) and Larsen (1985), are based primarily on radiocarbon dating of inter-ridge basal marshes, but also on interpretations of depositional rates. Along a baseline drawn essentially north-south parallel to the north-south shoreline of the central part of the plain, the age of successive ridges and the distance along the baseline provide a means of computing an average annual rate of southward advance equal to 33 ft/yr.

4.30 Figure 4.6 shows projected shorelines that would have developed in the absence of Waukegan Harbor. The projected shorelines are based on the beach ridge morphology and on the advance rate of 33 ft/yr. This projection suggests that under natural advance of the plain the 1995 shoreline would have been about at its present location on the north side of the harbor. By 2100 the shoreline would have reached just lakeward of the end of the south jetty.

4.31 The significant aspect of this shoreline projection is that, if no obstruction to littoral transport had been built in the Waukegan vicinity, littoral sediment from the north would still have been deposited in this area. The structures to protect the harbor entrance have trapped sediment to cause updrift accretion, and the configuration of this accretion is different than would have occurred without any structures, but accretion would have occurred either way. What has been deprived is the accretion that would have occurred south of the present harbor entrance. For example, much of the area presently occupied by the small-boat basin would be land if the natural trend of beach accretion had not been disrupted. What has also been deprived is the broad area of nearshore accretion that would blanket the lake bottom to the south of the advancing beach-ridge plain. This nearshore accretion area would likely have extended southward to the nearshore off the North Chicago shore.

4.32 The coastal setting of Waukegan Harbor is significantly different from the settings of other Corps-maintained commercial harbors in southern Lake Michigan such as St. Joseph, Michigan, Michigan City, Indiana, or Kenosha, Wisconsin. In each of these latter, the harbor entrance jetties occur along a rather linear shoreline, and no significant accretion of littoral sediment would have occurred if the structures were absent. The coastal setting for the jetty construction at Waukegan does not fit the typical case because this harbor was built at the shoreline reentrant of the downdrift end of a prograding beach-ridge plain. Because the harbor

was built in a net accretional area, the harbor construction locally altered and eliminated accretional trends that would have naturally occurred.

4.33 If Waukegan harbor had not been built, the littoral system of the Illinois coast would not have permanently lost the approximate 2.5 million cu yds of sand (2.1 million cu yds in-place) that was dredged from the harbor and disposed in deep water. This loss of sand resource has been the most detrimental impact to the coastal system related to the harbor. If the sand had been artificially bypassed, the severe nearshore erosion immediately downdrift of Waukegan Harbor (Fig. 3.1) could have been alleviated.

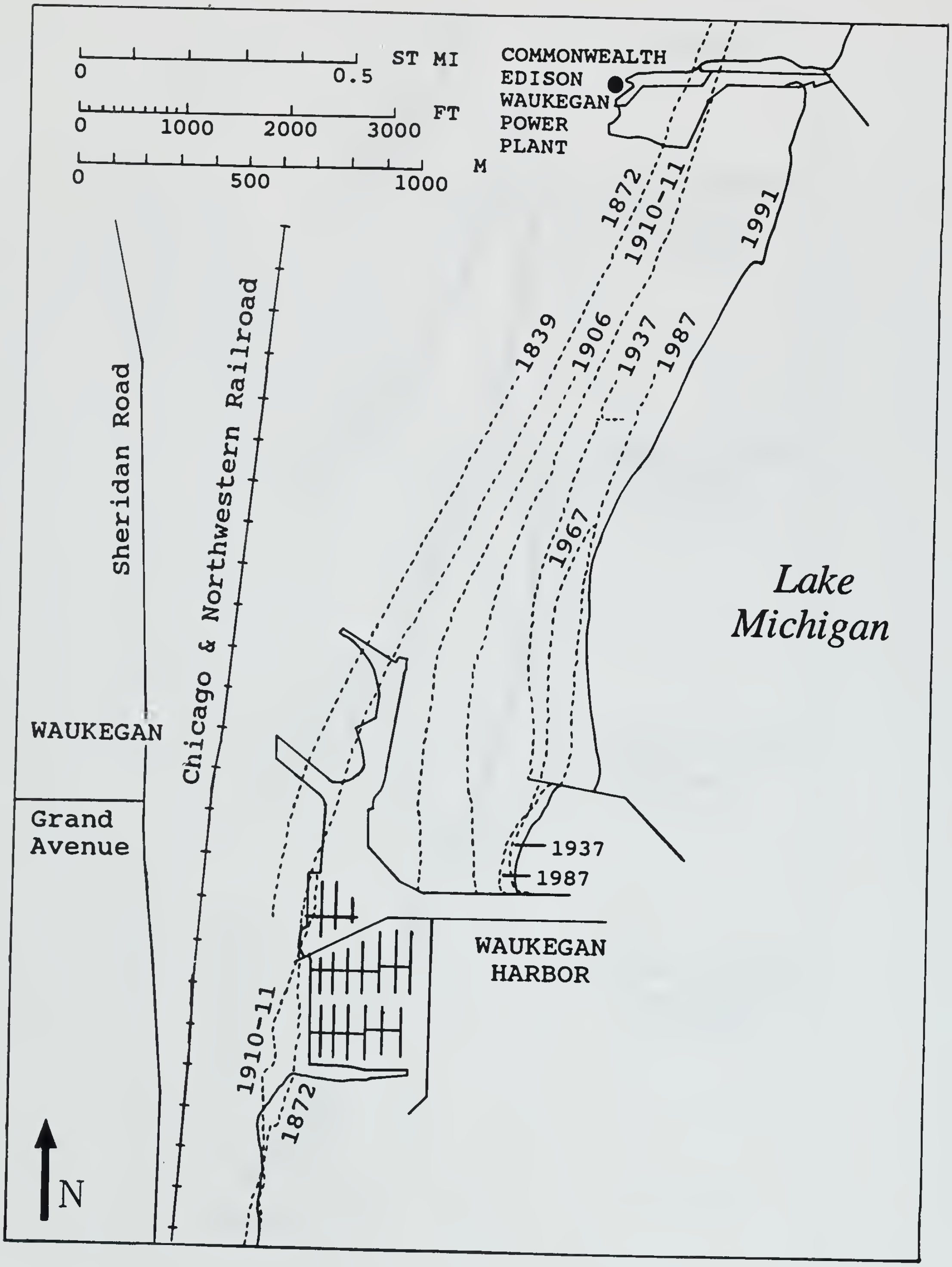

Figure 4.4. Historical shorelines documenting accretion on the updrift side of Waukegan Harbor. Shorelines are for lake levels at the time of mapping and are not corrected to Low Water Datum except for the 1910-11 shoreline (from Chrzastowski and Trask, 1992).

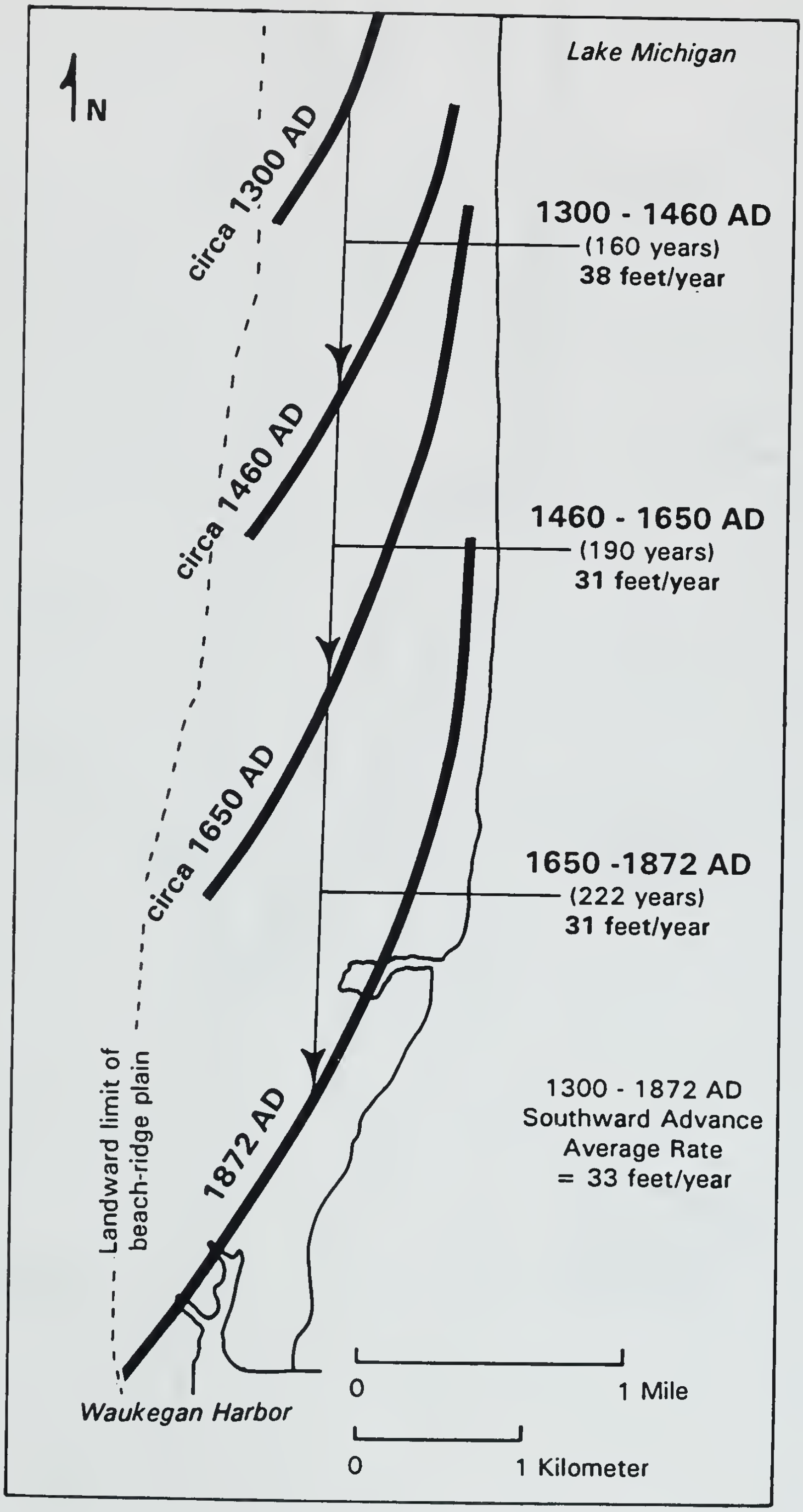

Figure 4.5. Beach ridges in the southern part of the Zion beach-ridge plain with assigned ages and computed rates of beach-ridge advance (after Collinson 1982 and Larsen, 1985).

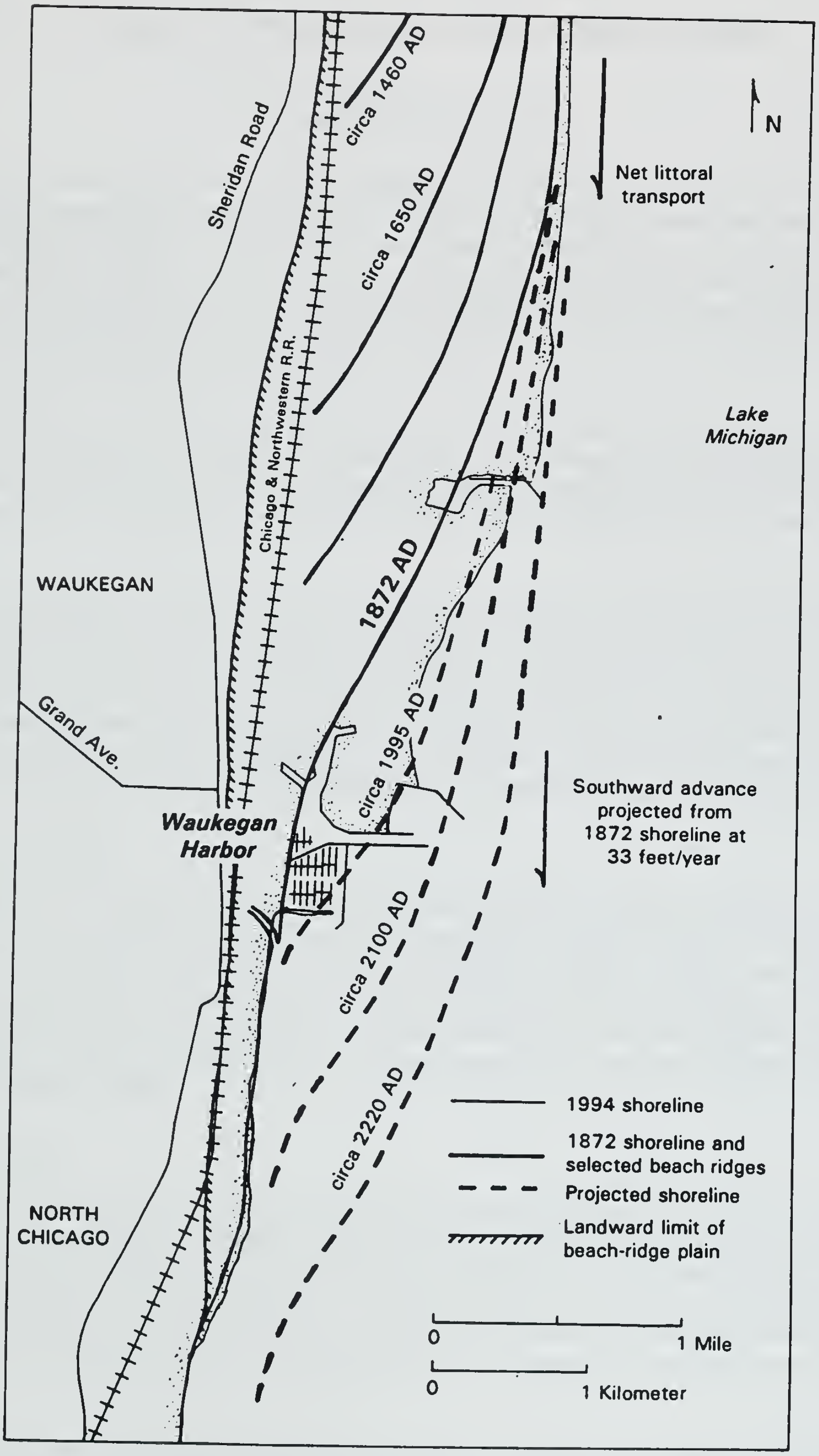

Figure 4.6. Projected shorelines for the Zion beach-ridge plain if Waukegan Harbor had not been built.

SECTION 5 COASTAL IMPACTS AT GREAT LAKES HARBOR

HARBOR DESCRIPTION

5.1 The harbor at Great Lakes Naval Training Center (here referred to as Great Lakes Harbor) is the largest breakwater-defended harbor or marina on the Illinois lakeshore north of Chicago. Unlike Waukegan Harbor, which was built along the downdrift end of a prograding beach-ridge plain, Great Lakes Harbor was built along a linear reach of the bluff coast. Ignoring the beach areas that have accreted inside this harbor since it was constructed, the breakwaters enclose an area of about 104 acres. By comparison, Waukegan Harbor and its adjoining marina total 80 acres, and North Point Marina totals 77 acres.

5.2 The harbor is formed by a pair of shore-attached breakwaters (Fig. 5.1). The north breakwater consists of two linear segments with a 120-degree elbow between them. The south breakwater is essentially linear except for a short, angled segment at the lakeward end. The harbor entrance occurs at the gap between the breakwaters and is open toward the southeast.

5.3 In the innermost harbor, pier moorage and a protected inner basin are formed by two shore-attached piers. This inner harbor corresponds to the mouth of Pettibone Creek, which flows down a ravine that cuts the adjacent uplands. Along the northern shore of the harbor is a broad beach area formed by some fill but primarily resulting from accretion of littoral sands. The breakwaters have a low crest elevation that allows waves to overtop them and transport littoral sand into the harbor. Along the southern shore of the harbor there has been some accretion, but primarily this is a fill area and has included spoil disposal from harbor dredging.

Construction History

5.4 The north pier and south pier that form the inner harbor appear on a 1910/11 bathymetric survey, and thus construction of the inner harbor pre-dates 1910. The north breakwater and south breakwater were constructed in 1923. Along their lengths, the breakwaters consist of a combination of several different structural designs. These are: 1) stone-filled concrete caissons; 2) pile-type rubble mounds with either limestone or granite caps; 3) stone-filled cribs with concrete caps. The structures are in various stages of deterioration (STS Consultants, 1988).

Dredging History

5.5 Some uncertainty exists concerning the dredging history of Great Lakes Harbor. Available data from the U. S. Department of the Navy suggest that in the 71-year history from 1923 to 1994, the harbor has only been dredged twice, in 1952 and 1970. Data on the volume of dredge material are lacking. In one or both of these years, some dredge material was dumped onshore in the southwest corner of the harbor, creating a beach-plain area; dredge spoil was also taken 5 miles offshore (U.S. Department of the Navy, unpublished records).

5.6 Comparison of bathymetric maps (sections 5.11 and 5.12) suggests that the harbor dredging apparently did not result in a removal of all material that had accumulated inside the harbor, but most likely was limited to maintaining desired depths across the central harbor area from the harbor entrance to the inner harbor.

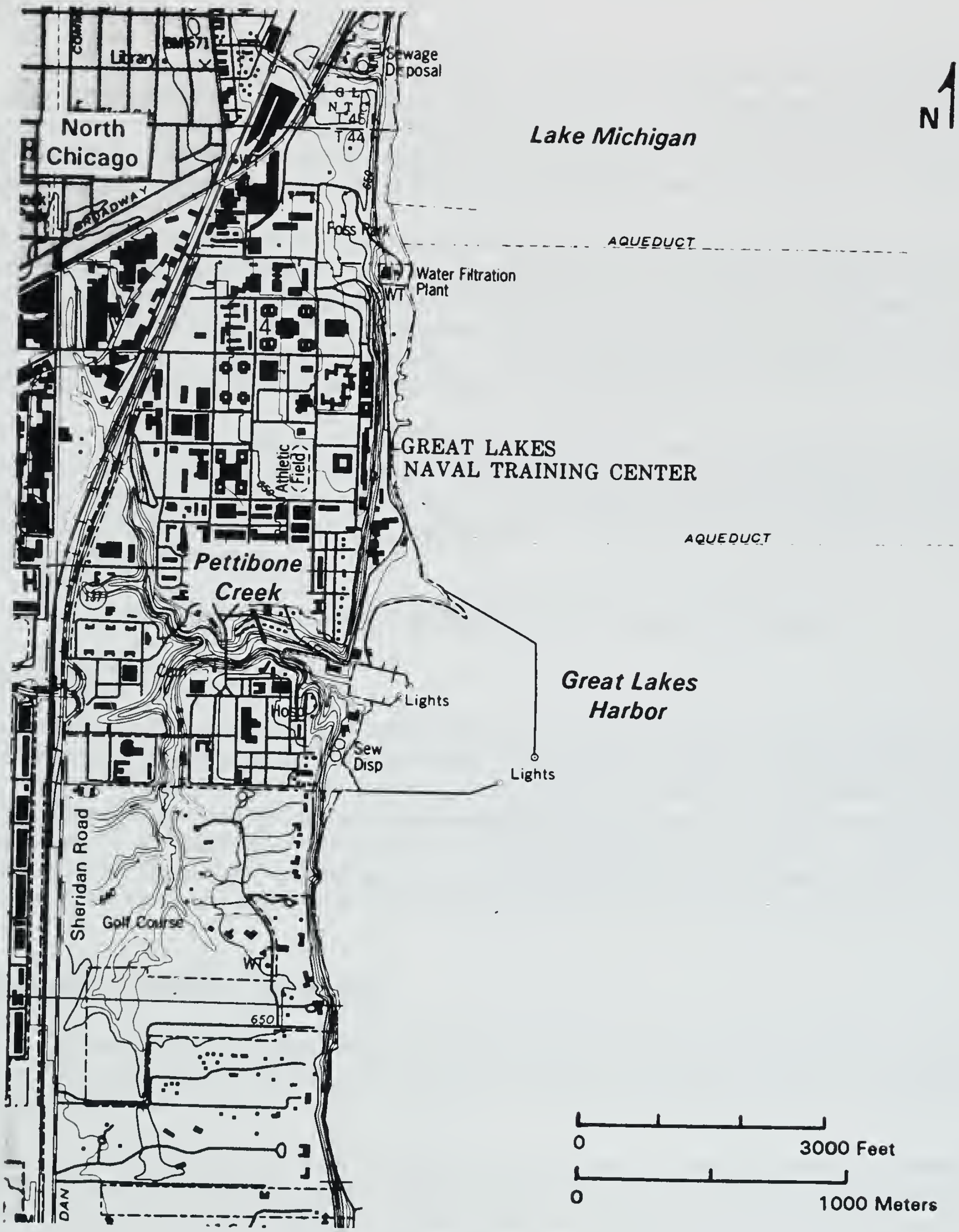

Figure 5.1. Location and configuration of Great Lakes Harbor.

Harbor Bathymetry

5.7 Bathymetric surveys of the harbor exist for 1910/11 (U.S. Lake Survey), 1954 (U.S. Department of the Navy), 1976 (Collinson *et al.*, 1979), and 1992 (Maguire Group, Inc.). The 1910 survey provides a pre-construction reference since the breakwaters had yet to be constructed and no harbor-induced lake-bottom accretion had occurred. The 1992 survey is recent enough relative to this report (1995) to approximate present conditions.

5.8 The 1992 bathymetry documents that the present-day harbor is essentially a concave basin with a channel (or trough) 12 to 15 ft deep (LWD) extending from the harbor entrance to the inner harbor. The bottom shoals northward and southwestward of this central deep water (Fig. 5.2). Shoaling in the northeast part of the harbor near the breakwater elbow is to such a degree that a sand island occurs here. This shoaling along the inner side of the north breakwater extends at least as far south as the harbor entrance.

5.9 The 1992 survey did not extend outside the harbor entrance to adequately map this accretionary feature, but the 12 ft LWD contour suggests that the southern edge of this accretion is south of the harbor entrance. The lake bottom across the harbor entrance is asymmetric with depths of 18 ft LWD near the south breakwater and depths of 9 to 12 ft LWD near the north breakwater.

HISTORY OF SEDIMENT ACCUMULATION INSIDE THE HARBOR

Mapping Methods

5.10 The volume of sediment that has accumulated inside the harbor can be evaluated based on comparison of the series of four bathymetric surveys (1910, 1954, 1976, and 1992). For each of these survey years, depth contours were drawn at a scale of 1:5000 and referenced to LWD. Successive map years were superimposed, and the intersection of contours provided control points to create an isopach map of sediment accretion and erosion. Areas within contours were measured by planimeter and were multiplied by the mid-contour value to give volume. Volumes were summed to give total accretion and erosion and net change.

Isopach Maps of Harbor Accumulation

5.11 Figures 5.3 and 5.4 show isopach maps for the comparisons of the three successive survey intervals (1910-1954; 1954-1976; 1976-1992) and a summary map for the 82-year interval 1910-1992.

5.12 The series of isopach maps indicates that the area of major sediment accumulation occurs in the northeastern half of the harbor adjacent to the two arms of the north breakwater. This is consistent with the net supply of littoral sediment from the north and with most of this supply being deposited in the harbor after being transported over the north breakwater. Sediment accumulation has also occurred in the southwestern half of the harbor against the south breakwater. This is consistent with a net southerly movement of sediment across the harbor area and with the south breakwater acting as a barrier.

Figure 5.2. 1992 bathymetry of Great Lakes Harbor. Contours are in feet referenced to Low Water Datum (modified from Maguire Group Inc., 1992).

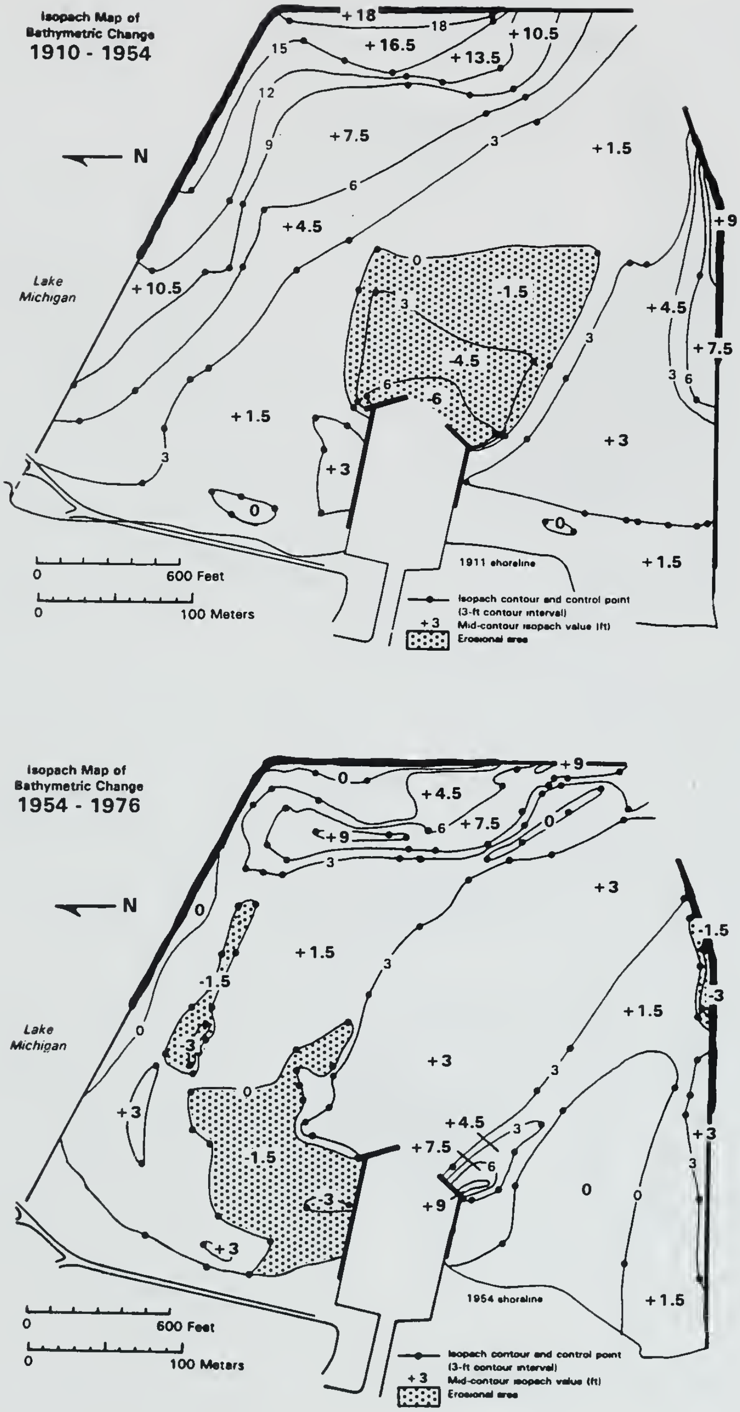

Figure 5.3. Isopach map of Great Lakes Harbor lake-bottom change based on comparison of bathymetry for 1910-1954 and 1954-1976. The breakwaters were constructed in 1923. Most lake-bottom accretion in the 1910-1954 comparison occurred subsequent to the 1923 breakwater construction. Some erosion near the inner harbor may have occurred between 1910 and 1923.

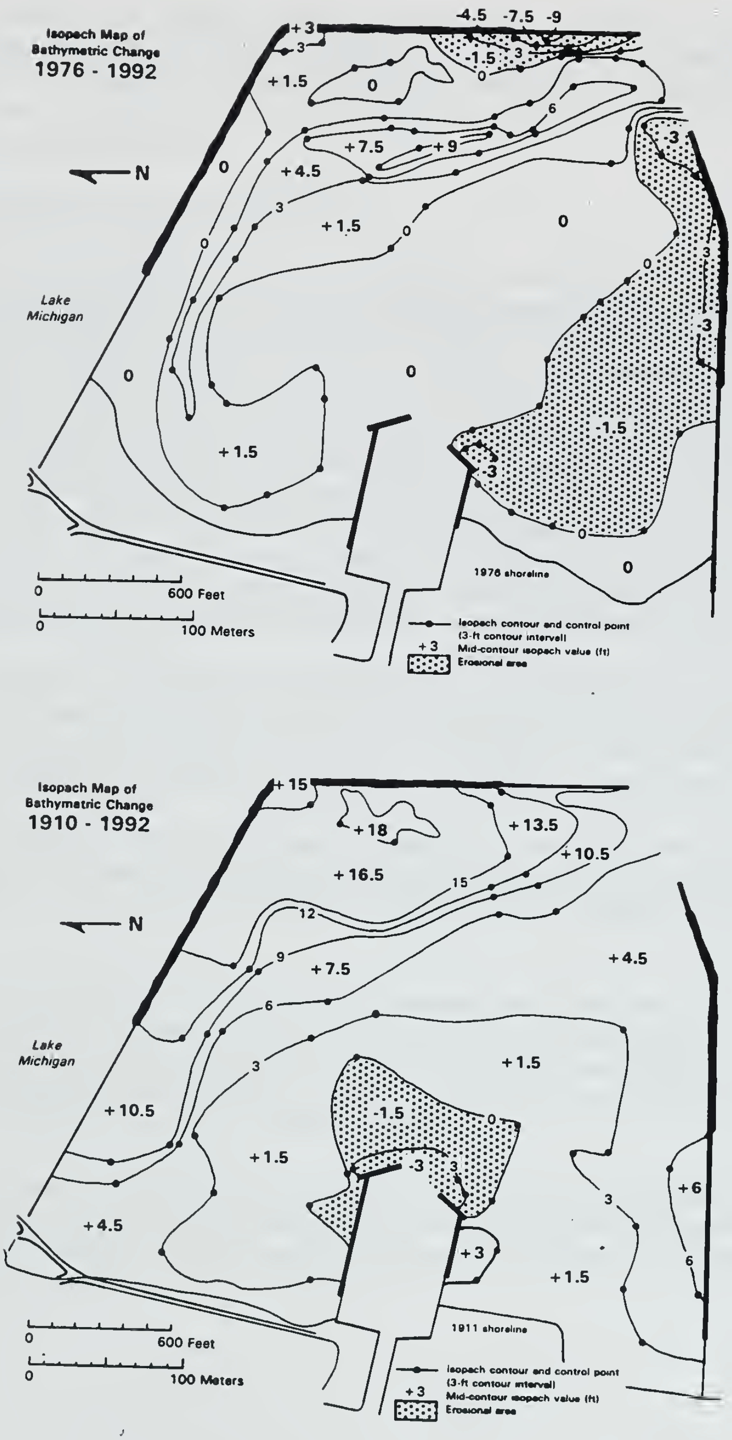

Figure 5.4. Isopach map of Great Lakes Harbor lake-bottom change based on comparison of bathymetry for 1976-1992 and 1910-1992. The 1910-1992 comparison presents the long-term record.

5.13 The net change is accretion in each map comparison. Some of the erosion in the 1910-1954 comparison and the 1954-1976 comparison may be a result of dredging that occurred in 1952 and 1970 respectively. In the 1976-1992 comparison, dredging is not a factor, and the erosion may represent a loss of sediment through the harbor entrance and/or a redistribution within the harbor.

Volumetric Analysis of Harbor Accumulation

5.14 Figure 5.5 summarizes the volumetric change for each of the three time comparisons. Volumes were computed by measuring the areas of net accretion and erosion, multiplying each area by the mid-contour value, and summing the results. Volumes have been rounded to the nearest 100 cubic yards. In the 1910-1954 comparison, the volumes are corrected for the space occupied by the subaqueous part of the breakwaters. For example, the breakwater is mapped as a linear feature, but this structure has a triangular cross section. In comparing bathymetric data before and after the breakwater construction, the subaqueous part of the breakwater could erroneously be accounted for as an accretional area. A volume correction for this subaqueous part of the breakwater was determined based on cross sections of the breakwaters shown on construction diagrams (STS Consultants, 1988). In the volume calculations done here, this correction was only needed in comparing post-construction bathymetric data with the 1910 bathymetric data, which is pre-construction.

5.15 The summation of the three comparisons gives a net accretion of 1,082,600 cu yds. As a check, by comparing the bathymetry of 1910 and 1992, the net accretion is 1,030,300 cu yds which is in agreement within 5 percent. Thus within Great Lakes Harbor, a total of slightly over 1 million cubic yards of sediment has been trapped since the harbor was built.

5.16 Figure 5.6 summarizes the volumetric change on an average annual basis for the three time comparisons. In reality, the rate likely varied significantly from year to year, but the average annual rates are a way to evaluate overall trends in accretion and erosion through time.

5.17 These average annual rates indicate a decreasing rate of accretion with time. Averaged over the first 31 years following construction (1923-1954), rapid infilling of the harbor was occurring at the rate of 22,100 cu yds/yr. Over the next 22 years (1954-1976) the average rate of infilling decreased to 14,100 cu yds/yr. During the next 16 years (1976-1992) the average rate of infilling decreased to 5,500 cu yds/yr.

5.18 The decrease in accretion volume with time cannot be attributed to a decrease in sediment supply. Beginning in 1977 the updrift sediment supply increased because prior to that time sediment dredged from Waukegan Harbor was disposed of offshore, but artificial bypassing began in 1977.

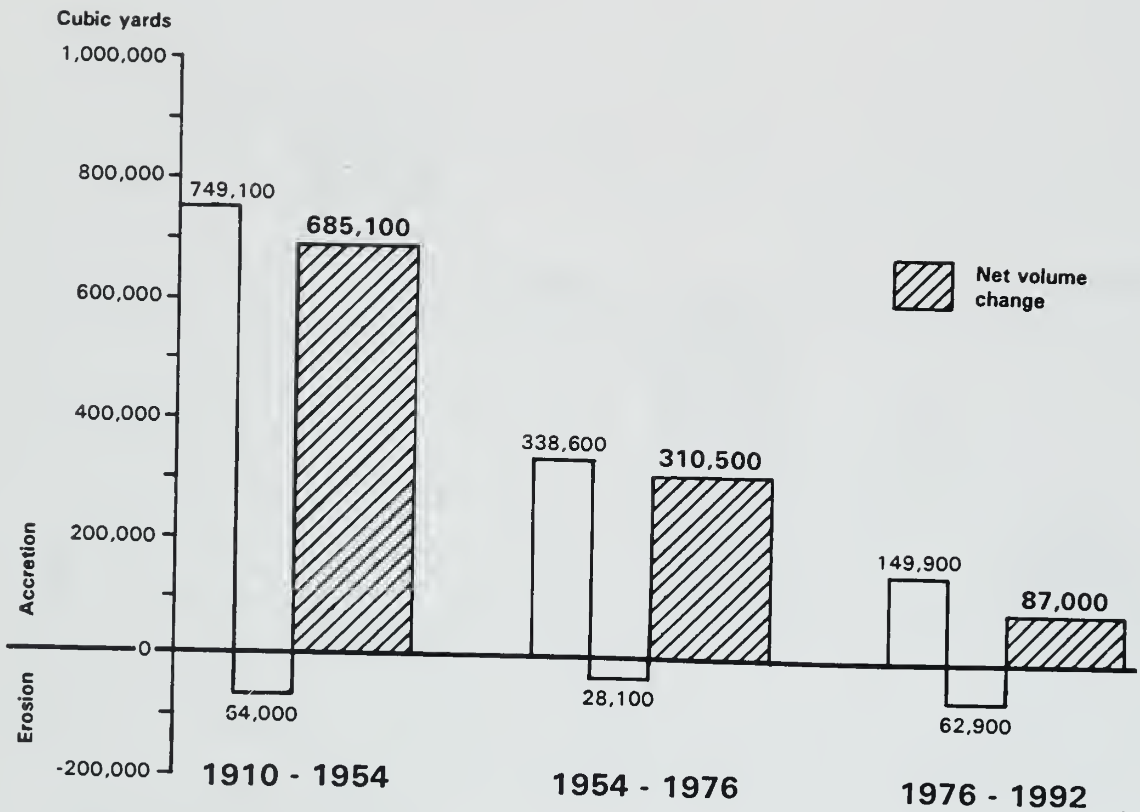

Figure 5.5. Volumes of accretion and erosion and net volume change within Great Lakes Harbor for three successive time intervals defined by bathymetric surveys. In the 1910-1954 comparison, some accretion and erosion could have occurred near the piers for the inner harbor which were constructed prior to 1910. Most of the accretion likely occurred after the construction of the breakwaters in 1923.

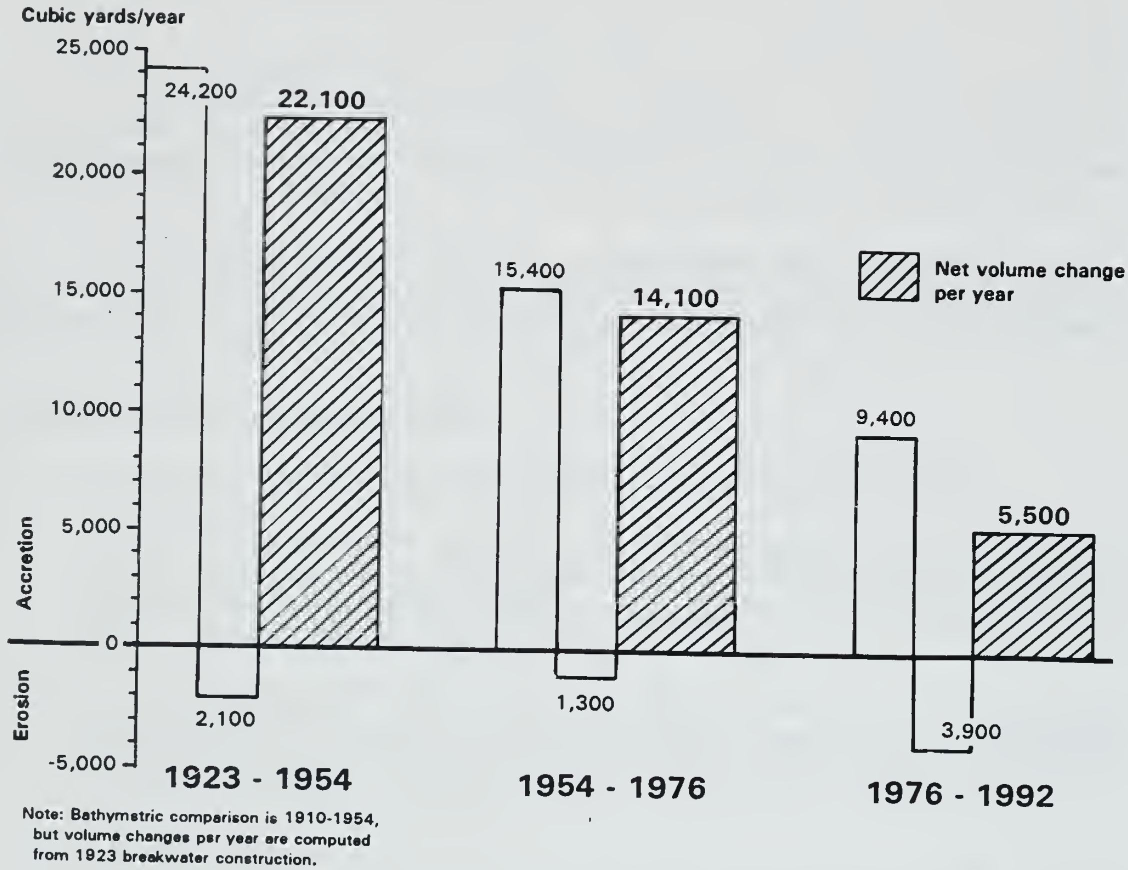

Figure 5.6. Average annual rates of accretion, erosion, and net volume change within Great Lakes Harbor for each of the three comparisons of harbor bathymetry. To compute the annual accretion rate for the 1910-1954 bathymetric comparison, 1923 was used as the beginning year since most accretion is assumed to have occurred after the breakwater construction.

5.19 Waukegan Harbor was a total to near-total barrier to littoral drift for the time when 92 percent of the sediment accreted inside Great Lakes Harbor (Fig. 5.5; 1910 [*i.e.*, 1923] to 1976). Although some of the entrapped sediment may have been derived from the natural bypass at Waukegan Harbor, the majority of the sediment that has infilled Great Lakes Harbor was likely derived from the nearshore erosion along the 3.4-mile nearshore between Waukegan Harbor and Great Lakes Harbor. The volume of nearshore erosion along this reach from 1910-1974 (Fig. 3.1) totals about 2.0 million cu yds (1,135,200 cu yds at Waukegan plus 821,800 cu yds at North Chicago), which is an average annual contribution of about 33,000 cu yds/yr. The supply estimate of 2.1 million cu yds is closely matched with the volume of net accretion within the harbor from 1923-1976 (995,600 cu yds; Fig. 5.5) and the additional accretion that occurred on the lakeward perimeter of the harbor (1,569,300 cu yds; see section 5.29-5.30).

5.20 The decreasing accretion with time suggests that Great Lakes Harbor may be approaching its infill capacity and a dynamic equilibrium. The shape of the harbor combined with local wave and current dynamics may be factors that will prevent much more sediment from accumulating here.

<u>Summary of Harbor Volumetric Changes</u>

5.21 The volumetric analysis of the harbor infilling can be summarized as follows:

1) Between the breakwater construction in 1923 and the most recent bathymetric survey in 1992, total volume of sediment accretion inside Great Lakes Harbor is slightly more than 1 million cu yds (1,082,600 cu yds). Considering all accumulation up to 1992, 92 percent occurred prior to 1976.

2) The rate of accretion within the harbor has been decreasing. In the interval 1923-1954 the average annual rate was 22,100 cu yds/yr. From 1954 to 1976 the rate was 14,100 cu yds/yr. By the interval 1976-1992 this rate had decreased to 5,500 cu yds/yr. Tetra Tech (1980) believed that the harbor was at or near capacity.

3) During the time when 92 percent of the sediment accumulation occurred within the harbor (1923-1976), no artificial bypass was occurring at Waukegan Harbor. The most likely source of littoral sediment that infilled Great Lakes Harbor during that period was from nearshore erosion along the 3.4-mile nearshore between Waukegan Harbor and Great Lakes Harbor. The accretionary prism lakeward and south of the harbor was probably not contributing significant material to the shoreline south of the harbor (Tetra Tech, 1980).

LAKE-BOTTOM CHANGES OUTSIDE THE HARBOR (1910-1974)

<u>Mapping Methods</u>

5.22 The ISGS collected bathymetric data inside Great Lakes Harbor in 1976. The lake-bottom outside the harbor was mapped by ISGS in 1974. Thus when comparing with the 1910 data, the timing of the ISGS data sets results in a two-year difference for the comparisons inside the harbor (1910-1976) and outside the harbor (1910-1974). The 1910 to 1974 bathymetric comparison outside the harbor provides a means of mapping the accretion and erosion around the perimeter of the harbor for the 51 years following construction (1923-1974). LWD contours were compared at a scale of 1:10,000.

Isopach Map of Lake-Bottom Changes Outside the Harbor

5.23 Figure 5.7 is an isopach map for the bathymetric comparison of 1910-1974 outside the harbor (1910-1976 inside the harbor). This is similar to the bathymetric comparison shown in Figures 3.1 and 3.2 but was produced to focus specifically on the harbor area.

5.24 The total nearshore area of changes in the vicinity of the harbor extended from about 0.9 mile updrift to about 1.8 miles downdrift. Both accretion and erosion occurred. The greatest concentration of accretion outside the harbor occurred on the updrift side of the north breakwater. Here, most of the accretion was greater than 3 ft, and accretion exceeding 12 feet occurred along part of the breakwater.

5.25 The accretion wedge of 3 to 12 ft on the north side of the breakwater continued in a narrow band against the lakeward side of the north-south segment of this breakwater. This was a transport pathway or "sand bridge" for the natural bypass of the harbor. The 3-ft accretion contour formed a lobe extending about 1150 ft southward from the north breakwater and harbor entrance. The main axis of this downdrift accretion area was shore-parallel and remained offshore essentially aligned to the path of bypass around the harbor. This pattern of accretion is indicative of the natural bypass of the harbor.

5.26 Mapping the accretion area downdrift from the harbor has some uncertainties such as defining a lakeward limit and determining the location and shape of the southern limit.

5.27 The 1910 to 1974 erosional zone downdrift from the harbor covers an area of beach and nearshore totalling 350 acres. The most severe erosion was located close to shore in a shore-parallel band extending from about 2000 to 4000 ft downdrift from the south breakwater. Within this band the maximum nearshore erosion was in the range 6 to 9 ft. Probing of this area in 1976 (Norby, 1981) and as recent as 1990/91 (Shabica and Pranschke, 1994) indicates that all sand has been removed and the lake bottom consists of exposed till.

Volumetric Analysis

5.28 Mid-contour values from the isopach map (Fig. 5.7) were used in computing accretion and erosion volumes. All volumes were corrected for the cross-sectional volume of the breakwaters. The distinction between updrift and downdrift is defined by a line drawn lakeward along the axis of the shore arm (*i.e.*, east-west arm) of the north breakwater. Thus, sediment that has accumulated along the east side of the north-south arm of the north breakwater is considered part of the downdrift volume.

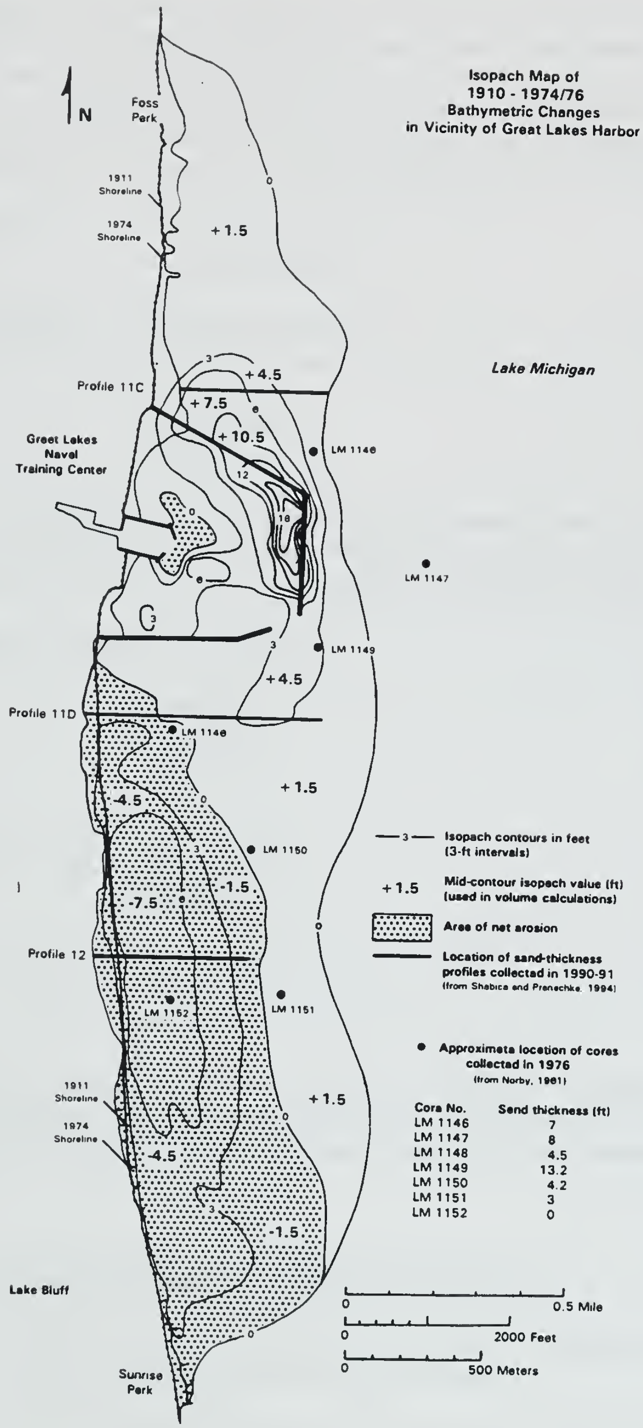

Figure 5.7. Isopach map of sediment accretion and erosion based on comparison of 1910 and 1974/76 bathymetry for the updrift and downdrift area of Great Lakes Harbor.

5.29 Annual changes were computed using a 53-year reference period (1923-1976) so that the data could be compared with the 1976 data from within the harbor. The average annual rates would be about 4 percent higher if a 51-year reference is used (1923-1974). The volumes calculated are specifically for the map area shown in Figure 5.7; thus these volumes differ from those in Table 3.1, which are computer based on municipal boundaries. Rounded to the nearest hundred, the volumes and annual rates of volume change are:

Updrift:	Total Accretion	754,600 cu yds
	Accretion/year	14,200 cu yds/yr
Downdrift:	Total Accretion	784,700 cu yds
	Accretion/year	14,800 cu yds/yr
	Total Erosion	2,125,000 cu yds
	Erosion/year	40,100 cu yds/yr

5.30 The volume analysis for inside the harbor gives an average net accretion rate of 18,800 cu yds/yr for the interval 1923-1976. Adding the harbor accretion to the updrift and downdrift accretion, and comparing to the erosion, the following summation results:

Total Accretion Volume (1923-1976)		
	Inside Harbor	995,600 cu yds
	Updrift	754,600
	Downdrift	784,700
	Summation	2,534,900 cu yds
Total Erosion Volume (1923-1976)		
	Downdrift	2,125,000 cu yds
Annual Accretion Rate (1923-1976)		47,800 cu yds/yr
Annual Erosion Rate (1923-1976)		40,100 cu yds/yr

5.31 The net change is accretion, but the total accretion and erosion differ by only about 16 percent. Thus, considering the map area in Figure 5.7 as a partially closed system, severe erosion downdrift of the harbor partially compensated the littoral stream for the accretion caused by the harbor.

Summary of Volumetric Changes Inside and Outside the Harbor

5.32 The volumetric analysis of lake-bottom changes within and adjacent to the harbor during the interval 1910 to 1974/76 can be summarized as follows:

1) In the first 53 years following construction of the Great Lakes Harbor breakwaters (1923-1976), this facility resulted in 2.5 million cubic yards of littoral sediment entrapment across a broad area extending updrift, downdrift, and within the harbor (Fig. 5.7).

2) In the first 53 years following construction of the breakwaters, 2.1 million cubic yards of sediment was eroded from the downdrift beaches and nearshore

in the 1.8-mile reach from the south breakwater to Sunrise Park. Additional erosion occurred along the beaches and coastal bluffs which liberated more sediment. The erosion was in part a result of natural erosional trends in the region, but the degree of erosion was accentuated because of the starvation of littoral sediment that occurred immediately downdrift of the harbor.

3) On an average annual basis, the 1923 to 1976 total net accretion associated with Great Lakes Harbor averaged 47,800 cu yds/yr.

4) On an average annual basis, the 1923 to 1976 total downdrift erosion associated with Great Lakes Harbor across the nearshore averaged 40,100 cu yds/yr. Additional sediment would have entered the littoral stream from associated beach and bluff recession.

LAKE-BOTTOM CHANGES OUTSIDE THE HARBOR (1974-1994)

5.33 Lake-bottom changes outside the harbor during the interval 1974 to 1994 are discussed in Sections 3.38 through 3.40 and shown on Figures 3.6 and 3.7. Erosion dominated during this time and involved erosion across areas that had been accretional in the earlier interval of 1910 to 1976. Maximum erosion was generally in the range 0 to 2 ft but locally reached 3 to 4 ft. Accretion occurred updrift of the north breakwater, lakeward of the east side of the north breakwater, and near the harbor entrance. Maximum accretion of 2 ft occurred east of the north breakwater.

PROJECTION OF FUTURE LAKE-BOTTOM CHANGES AT THE HARBOR

Inside the Harbor

5.34 The volumetric analysis within the harbor (sections 5.14 - 5.20) indicates that the rate of accretion within the harbor has been decreasing with time (Fig. 5.6). The implication is that entrapment inside the harbor is reaching or has reached a dynamic equilibrium at which no significant future net change will occur.

5.35 Great Lakes Harbor has long been regarded as a major trap for littoral sediment along the Illinois coast. The volumetric analysis of this study indicates that the history of entrapment within the harbor may be coming to an end.

5.36 The bathymetry collected in 1992 (Fig. 5.2) shows that there is still some deep water in the central area of the harbor, and that shoaling against the south breakwater is not as severe as that on the north breakwater. Thus there is space within the harbor for further accretion. However, the interaction of local wave dynamics, currents, shape of the harbor breakwaters, and possibly configuration of the harbor entrance and the updrift fillet beach are apparently factors that are contributing to a limitation on the degree of harbor infilling. Changes to the configuration and/or height of the breakwaters will disrupt this equilibrium and accretion or erosion could result. The equilibrium is also dependent on local sediment budget. If the updrift sediment supply is diminished, erosion could occur for some time within the harbor until a new dynamic equilibrium is established.

Outside the Harbor

5.37 The lake-bottom changes outside the harbor, documented in the comparison of the 1974-1994 bathymetry (Figs. 3.6 and 3.7), suggest that erosion will dominate the harbor perimeter as the lake bottom adjusts to a decreased supply of littoral sediment. Most of the accretionary wedge updrift of the north breakwater will persist, but erosion will restrict how far lakeward the wedge extends. Erosion will likely remove most or all of the former accretion along the eastern side of the north breakwater. Erosion will continue to reduce the thickness of the former accretionary area downdrift of the harbor.

COASTAL EVOLUTION IF GREAT LAKES HARBOR HAD NOT BEEN BUILT

5.38 The 1923 construction of the breakwaters for Great Lakes Harbor introduced an obstruction along a reach of bluff coast where no naturally occurring obstructions existed. All of the local accretion and the severity of the local downdrift erosion can be attributed to this harbor, which has trapped littoral sediment, deprived downdrift areas of littoral sediment, and altered local wave and current dynamics.

5.39 If the harbor had not been built, no obstruction would be at this site for the littoral sediment moving southward from the nearshore erosional area south of Waukegan Harbor. Thus the total of 2.5 million cu yds of sediment that accumulated within the harbor and in the harbor vicinity between 1923 and 1976 would have been able to migrate southward and nourish the beaches and nearshore along the bluff coast.

5.40 Without construction of the harbor, the deprivation of littoral sediment on the downdrift side of the harbor would not have occurred. Nearshore erosion and shoreline and bluff recession would have occurred along the Lake Bluff shore if the harbor had not been built. Erosion was the naturally occurring coastal process. However, without the harbor construction, the degree of erosion observed over the past 70-plus years along the Lake Bluff coast would not have been as severe.

SECTION 6 COASTAL IMPACTS AT FOREST PARK BEACH

NOTE ON FEDERAL INTEREST

6.1 There has been no federal involvement in the construction of Forest Park Beach other than the regulatory process. The facility is discussed here because federal permits for the project are still under review and the Corps is presently evaluating data from an ongoing coastal monitoring program.

FACILITY DESCRIPTION

6.2 Forest Park Beach is a 22-acre lakeshore facility at Lake Forest, Illinois, built by the City of Lake Forest for shore protection and lakeshore recreation. The facility consists of an arcuate series of rubble-mound breakwaters that form a series of four crescent-shaped beach cells. The project also includes a small-boat basin, rubble-mound revetment, parking, walkways, and several recreational buildings.

6.3 The facility is primarily shore-parallel in plan view. The maximum offshore protrusion is 410 ft lakeward of the preconstruction shoreline. Water depths within 25 ft of the lakeward side of the breakwaters (as of the 1994 surveys) are no more than 8 ft LWD. Prior to construction of this facility, this area of lakeshore was a seriously eroding park beach. A groin field provided minimal shore protection.

Construction History

6.4 The City of Lake Forest financed construction of this $9-million dollar facility. The project design, testing, and construction history are summarized by Anglin *et al.* (1987). Work began in 1986 and was completed in 1987. In order to assure stability of the beaches, the beach cells were filled with a fine gravel of median diameter 2.8 mm, commonly called "bird's eye."

Dredging History of Small-Boat Basin

6.5 Maintenance dredging is required for the small-boat basin and the approach to the basin in order to maintain a minimum depth of about 5 ft LWD. Table 6.1 summarizes the dredging history. The first dredging occurred in 1989, two years after the project completion, and has been required every year since. The material dredged has consistently been fine sand. The total volume dredged from 1989 to 1994 equals 16,920 cu yds. For the six years of dredging, this gives an average annual dredging volume of about 2,800 cu yds/yr. All sediment dredged is dumped about 1800 ft south (downdrift) of the south end of Forest Park Beach in water depths less than 10 ft.

Table 6.1. Dredging volumes for Forest Park Beach small-boat basin.[1]	
Year	Dredge Volume (Cubic Yards)
1993	1,845
1992	4,975
1991	1,800
1992	3,600
1993	2,600
1994	2,100
Summation	**16,920**
Average Annual Volume	**2,820**

[1]Data provided by City of Lake Forest.

History of Nearshore Nourishment

6.6 During the summers of 1991, 1992, and 1993, the City of Lake Forest placed nourishment sand into the nearshore on the downdrift (south) end of the project. The three years of nourishment totaled about 10,000 cu yds. This was done to compensate for updrift accretion documented in the first of two post-construction monitoring programs.

Coastal Monitoring Program

6.7 A three-year monitoring program of repetitive beach and nearshore profiling occurred following construction (1987/88/89). This monitoring determined that accretion had occurred on the updrift beach as well as in a nearshore bar (Lake Forest Shoreline Monitoring Committee, 1990). To further assess coastal impacts of the project, a five-year monitoring program began in 1991 and will be completed in summer 1995.

6.8 Annual reports of this coastal monitoring are prepared by the City of Lake Forest (CH2M Hill, 1992; Magnus, 1993a, 1993b; 1994). Review of these reports, and additional data and evaluation of coastal processes, are presented in reports by the Illinois State Geological Survey (Chrzastowski and Trask, 1992, 1994; Trask and Chrzastowski, 1993, 1995).

LAKE-BOTTOM CHANGES

6.9 The coastal monitoring at Forest Park Beach is still an ongoing project, and thus no final summary of observations has been done. Data collected thus far (1987-1994) have

documented that the project has acted as a partial barrier to littoral transport. However, no detrimental impacts of erosion have been identified along the shore immediately downdrift of the project.

6.10 Entrapment has occurred in all four of the beach cells. The major accretion is associated with a wedge of sand building around the lakeward perimeter of the breakwaters. This is a bypass pathway or "sand bridge" which will eventually reach the southern end of the project and facilitate natural bypass of littoral sediment. As of summer 1994, the southern leading edge of this accretion wedge was lakeward of the southernmost breakwater. Thus, as of 1994, this sand bridge had extended along about two thirds of the lakeward perimeter of the facility. Although this accretion wedge does not go completely around the facility, some degree of natural bypass is documented by entrapment of sand in the small-boat basin which is farther downdrift than the leading edge of the accretion wedge. Natural bypass may also be responsible for some of the accretion that has occurred along the beaches and nearshore downdrift of the facility.

6.11 Evaluation by the ISGS indicates that, at a threshold of one-foot annual lake-bottom change for 1987 through 1992, and a zero-foot threshold from 1992 through 1994, both erosion and accretion had occurred within the monitoring area in the first seven years following construction. The net change was accretion. The net accretion volume for all accretionary areas adjacent to the facility (*i.e.*, updrift, within the beach cells, and within the extent of the sand bridge) totals 65,600 cu yds (Trask and Chrzastowski, 1995). This is a seven-year average annual accretion of 9,400 cu yds/yr.

6.12 Several thousand to tens of thousands additional cubic yards of accretion will likely occur in completing the sand bridge to the shore south of the facility. As this sand bridge extends across the entrance to the small-boat basin, increased frequency of maintenance dredging will be necessary.

6.13 Persistence of accretion on the lakeward perimeter is dependent on the local sediment budget. If the updrift sediment supply is diminished, sand that has accreted within the sand bridge will likely erode in a manner similar to the erosion that occurred on the perimeter of Great Lakes Harbor between 1976 and 1994 .

COASTAL EVOLUTION IF FOREST PARK BEACH HAD NOT BEEN BUILT

6.14 Forest Park Beach has acted as a partial barrier to littoral transport. If the project had not been built, no other natural features or shore structures would cause the net accretion that has been documented in the beach cells and lakeward perimeter of this facility. Littoral sediment that has accumulated at this facility would have continued in southward transport along the littoral zone.

SECTION 7 NEARSHORE SEDIMENT BUDGET

GENERAL STATEMENT

7.1 The objective of this analysis was to develop a first-approximation sediment budget for the nearshore zone to assist in planning sand management. No previous study has prepared a nearshore budget for the study area. Previous work resulted in an estimate of littoral transport rate for this reach of the Illinois coast equalling 57,000 cu yds/yr based on profile comparisons from 1872, 1909/11, and 1946 (U.S. Army Corps of Engineers, 1953). Although this rate may not be maintained today, this can be assumed to be the "natural state" transport rate existing prior to significant human modification.

7.2 Data limitations made it difficult to develop a budget that could account for all gains and losses. These data limitations required that this "budget" be qualitative rather than quantitative, and the discussion simply presents the components of the budget that are known. Many additional components need to be quantified and incorporated before a thorough budget can be developed for this coastal reach. The following discussion considers the nearshore sediment budget for the two time periods of nearshore changes that have been evaluated in this report. A nearshore budget for 1910 to 1974 is considered for historical perspective. The budget for 1974 to 1994 is considered for recent and present-day conditions.

NEARSHORE SEDIMENT BUDGET 1910-1974

<u>Waukegan Harbor to Great Lakes Harbor</u>

7.4 During the interval 1910 to 1974 Waukegan Harbor was acting as a total to near-total barrier to littoral transport. No artificial bypass was occurring, but limited natural bypass occurred as is documented by the accretionary area downdrift of the harbor jetties (Fig. 3.1). The approximate volume of this accretion is 1.6 million cu yds (Table 3.1). On an annual basis, this was a minimum natural bypass of about 25,000 cu yds/yr. These volume estimates of natural bypass are based on what accreted downdrift of the jetties. An additional volume of bypass may have occurred that was not part of this accretion and was transported downdrift.

7.5 Shore defense along the industrial/commercial shoreline in this reach prevented any significant shoreline erosion. The volume estimate for the nearshore erosion along this reach for these 64 years is 2.0 million cu yds (section 5.19). A thick and extensive sand supply was available in this nearshore area because this was the subaqueous section of the southern part of the Zion beach-ridge plain. The cross section in Figure 2.3 provides an example of the abundance of sand that could have been available in this nearshore area; no nearshore area of the bluff coast had equivalent thicknesses of nearshore sand. The annual contribution to the littoral stream from this nearshore erosion was about 33,000 cu yds/yr. This contribution was likely the primary supply of littoral sediment approaching Great Lakes Harbor.

<u>Great Lakes Harbor</u>

7.6 Prior to the 1923 construction of the harbor breakwaters, the littoral sediment supply moving south from the nearshore erosion at Waukegan and North Chicago would have been transported past the Naval Training Center. Construction of the breakwaters blocked this transport. Total accretion within and bordering the harbor prior to 1976 was approximately 2.5 million cu yds (section 5.29). This required an annual supply (1923-1976) of about 47,000 cu yds/yr. The close agreement in terms of erosion volume between Waukegan Harbor

and Great Lakes Harbor (2.1 million cu yds) and the accretion at Great Lakes Harbor (2.5 million cu yds) is consistent with the assumption that this nearshore erosion was the primary source for sediment that accumulated at Great Lakes Harbor.

<u>Great Lakes Harbor to Wilmette Harbor</u>

7.7 This interval predates construction of Forest Park Beach, and thus the reach from Great Lakes Harbor to Wilmette Harbor was a single littoral cell. Nearshore erosion along a reach extending 1.8 miles downdrift from Great Lakes Harbor totalled about 2.1 million cu yds (Section 5.29). This gives an average annual rate of 40,100 cu yds/yr. This nearshore erosion volume is in close agreement with the accretion volume (2.5 million cu yds) associated with the harbor. There was additional input of littoral sediment from the local beach and bluff recession. The shoreline recession here reached as much as 500 ft (State of Illinois Division of Waterways, 1958).

7.8 Nearshore erosion was the net change as far south as Highland Park. Nearshore accretion was the net change from Highland Park southward to Wilmette Harbor. Sediment input to this net accretion can be attributed to the littoral sediment supply from updrift, and beach and bluff erosion. During part of this time interval many sections of bluff along this reach were yet to be defended from erosion. Data limitations prevent quantifying a budget along this reach for this time period.

NEARSHORE SEDIMENT BUDGET 1974-1994

<u>Waukegan Harbor to Great Lakes Harbor</u>

7.9 Artificial bypass of dredge spoil from Waukegan Harbor provided an input of nearly 579,000 cu yds (Table 4.2). First in 1977 a volume of 130,000 cu yds was bypassed to the south side of the harbor. Since 1984 the spoil has been placed in the designated disposal area south of the harbor. For the 10 years of continuous artificial bypass (1984-1994), the total bypass volume was 448,647 cu yds, which is an average annual bypass of about 44,900 cu yds/yr.

7.10 The major accretion area between these two harbors during this interval occurred at the dredge disposal site (Fig. 3.6). A volume estimate for this accretion mound based on the 1974-1994 bathymetric comparison is 181,500 cu yds. The 1994 data were collected within one to two months of disposal of the 1994 dredge spoil; thus some of this accretion pile may have been recent spoil that had yet to be dispersed by littoral currents. The total accretion volume (181,500 cu yds) is about 40 percent of the total volume of sediment that has been dumped here since 1984 (448,647 cu yds; Table 4.2). Thus about 40 percent of the total contribution to the site has not become part of the littoral transport.

7.10 Natural bypass of Waukegan Harbor also occurred during this time as documented by the accretion downdrift of the Waukegan Harbor jetties (Fig. 3.6). Most of the accretion lobe that had developed between 1910 and 1974 had become erosional during the 1974 to 1994 interval. This erosion was an added input to the littoral stream. In general, nearshore erosion dominated nearly all of the reach from Waukegan Harbor to Great Lakes Harbor. The combined nearshore for Waukegan and North Chicago had a net erosional volume of 840,600 cu yds (Table 3.2) which is an average annual volume of 42,000 cu yds/yr. Some of this was fine-grained sediment derived from erosion of the lake-bottom till; some was sand which was an additional supply to the littoral stream.

Great Lakes Harbor

7.11 Net accretion within the harbor from 1976 to 1992 totalled 87,000 cu yds which is an average annual net accretion of 5,500 cu yds/yr (Figs. 5.5 and 5.6). During the interval 1974-1994, the harbor interior was therefore not a significant sediment trap. The updrift fillet beach was also no longer a significant trap as it apparently had reached capacity. Some erosion even occurred along the most lakeward part of this accretion wedge. Erosion dominated the lakeward perimeter of the harbor in what had been the sand bridge for bypass prior to 1974. Thus, not only was natural bypass occurring at the harbor, but areas of former net accretion in the pathway for natural bypass had become areas of net erosion.

Great Lakes Harbor to Forest Park Beach

7.12 Erosion dominated the nearshore updrift of Forest Park Beach and across the nearshore lakeward of this facility. Some of the nearshore erosion was across till, which would yield primarily silt and clay of no consequence to littoral sediment supply. Since natural bypass was occurring at Great Lakes Harbor, sand in transport along this reach could be derived from nearshore erosion as far north as the nearshore of North Chicago and Waukegan, and also from the sand supply from artificial bypass of Waukegan Harbor. Prior to construction of Forest Park Beach, much of this supply would have been in transport past this site. Completion of the facility in 1987 formed a partial barrier.

Forest Park Beach

7.13 Accretion at this facility since its completion in 1987 has totalled 65,600 cu yds for all accretion in the beach cells and on the lakeward perimeter. On an annual basis this is 9,400 cu yds/yr (section 6.11). The facility has also trapped sand in the small-boat basin. Dredging in the small-boat basin since 1989 has removed 16,920 cu yds which is an average annual entrapment of 2,800 cu yds/yr (Table 6.1). The dredge spoil is returned to the littoral stream downdrift of the facility. The entrapment at the harbor suggests that some natural bypass of the facility has been occurring, though some of this may be a result of northward drift from the south during infrequent times of drift reversal with southeasterly winds. The volume of natural bypass to areas south of the small-boat basin is not known.

7.14 An input of littoral sediment at Forest Park Beach has resulted from sacrificial nearshore nourishment. Between 1991 and 1993, the City of Lake Forest supplied a total of 10,000 cu yds of nourishment to the nearshore on the downdrift side of the facility. This sediment contribution was to compensate for the volume of accretion in a nearshore bar formed on the updrift side of the facility soon after project completion.

Forest Park Beach to Wilmette Harbor

7.14 Insufficient data prevents evaluating a sediment budget along this reach for the interval 1974-1994. Profile comparisons indicate that erosion has dominated across the beaches and nearshore (Shabica *et al.*, 1991; Shabica and Pranschke, 1994). Sediment input from bluff erosion was likely insignificant during this interval considering the degree of bluff defense. Dredging at Wilmette Harbor removes, on average, about 12,000 cu yds/yr (City of Wilmette, pers. comm.). Approximately 11,000 cu yds/yr is artificially bypassed and 1,000 cu yds/yr is placed on an updrift beach. Natural bypass also occurs but the volume is not known.

PRESENT-DAY (1994) NEARSHORE BUDGET

7.15 The sediment budget for the time period 1974-1994 provides a reference to summarize key components of the present-day sediment budget in the study area.

1) Artificial and natural bypass of sediment from Waukegan Harbor is a primary supply of littoral sediment to the northern (updrift) end of the study area.

2) Nearshore erosion between Waukegan Harbor and Great Lakes Harbor is an additional input of littoral sediment to the updrift end of the study area. The contribution from this source is likely decreasing with time as sand resources in the nearshore are being depleted.

3) Great Lakes Harbor is no longer a major sediment trap compared to earlier in its post-construction history. Entrapment within the harbor may currently total less than 5,500 cu yds/yr. No significant accretion is occurring on the lakeward side of the harbor. Former areas of accretion along the lakeward perimeter of the harbor have become erosional areas and a source of sand for the littoral stream.

4) Since 1987, Forest Park Beach has been the first major barrier to littoral drift downdrift of Waukegan Harbor. The source of sand that has accumulated here can be assumed to be derived from the artificial bypass of Waukegan Harbor and from the nearshore erosion of sand occurring from Waukegan Harbor to Lake Forest. The natural bypass of Great Lakes Harbor allows the sand supplies from the nearshore of Waukegan, North Chicago, and Great Lakes Naval Training Center to reach Forest Park Beach.

5) Natural bypass of Forest Park Beach is indicated by the sediment accretion in the small-boat basin at the downdrift end of the facility. It is uncertain what percentage of littoral sediment approaching the facility is trapped and what percentage bypasses. The historical transition from accretion to erosion on the lakeward perimeter of Great Lakes Harbor suggests that a similar transition could take place at Forest Park Beach if changes occur in the sediment budget.

6) Between Forest Park Beach and Wilmette Harbor a source of littoral sediment is from beach and nearshore erosion. Wilmette Harbor is presently the major sediment trap in the study area, exceeding the entrapment at Forest park Beach by about 2-3,000 cu yds/yr.

7) A minimum estimate of the volume of littoral transport leaving the downdrift end of the study area is about 11,000 cu yds/yr based on the volumes for dredging and artificial bypass at Wilmette Harbor. The actual volume of sediment leaving the study area is greater by the unknown volume of natural bypass occurring at Wilmette.

8) Completion of a nearshore sediment budget for the study area needs to consider the inputs from bluff erosion, and the potential loss of nearshore sand by offshore transport and ice transport. Recent work by Barnes *et al.* (1994) address the issue of beach and nearshore erosion by ice. An additional input of nearshore sand could be derived by onshore transport from offshore sand reservoirs mapped by Foster and Folger (1994) and Foster *et al.* (1995).

SECTION 8 PROJECTED COASTAL CHANGE

General Comment

8.1 Projections of future coastal changes over the next 50 years are complicated by uncertainties concerning littoral sediment supply, lake-level changes, storm frequency and intensity, and human intervention. Assuming these variables remain as in the recent past, the following generalizations can be projected.

Waukegan Harbor to Great Lakes Harbor

8.2 Nearshore sand cover within most of the northern half of this reach is less than 4 ft thick (Foster *et al.*, 1995). Despite the supply of dredge spoil from the artificial bypass of Waukegan Harbor, much of the nearshore could be stripped of sand cover in the next 50 years. If the sand supply from artificial bypass is diminished or eliminated, the nearshore sand loss will occur more rapidly. As sand cover is lost, downcutting of the glacial till will follow. The shore along Waukegan and North Chicago has avoided shoreline recession because of riprap shore defense. Over the next 50 years, continued nearshore erosion and steepening of the shoreface profile could undermine these structures. As the line of defense is damaged, erosion will extend rapidly landward. The shore of Waukegan and much of North Chicago is beach-ridge plain. Along this shoreline, recession rates reaching a maximum of about 10 ft/yr are not unreasonable based on documented beach-ridge plain recession rates near the present site of North Point Marina (U.S. Army Corps of Engineers, 1953; Chrzastowski *et al.*, 1993).

Great Lakes Harbor to Forest Park Beach

8.3 Continued depletion of nearshore sand resources over the next 50 years could result in lake-bottom erosion undermining the breakwaters at Great Lakes Harbor. There had been net accretion around the lakeward perimeter of these breakwaters prior to 1974, but the 1974-1994 bathymetric comparison indicates that most of the former accretional areas have become erosional. The most serious threat of coastal storm damage in the study area occurs along the Lake Bluff shore. Here the nearshore profile has already been substantially over-steepened. Eventually, the existing shore-defense structures could be undermined and fail. If this occurs, rapid and catastrophic bluff recession could follow. As nearshore sand resources are continually depleted, the sand bridge around Forest Park Beach will be eroded. This facility has been an accretional area since 1987, but erosion will occur as updrift littoral supply is diminished. As the sand cover is lost, lake-bottom downcutting could result in undermining of the breakwaters at Forest Park Beach.

Forest Park Beach to Wilmette Harbor

8.4 At present, till exposures in the nearshore are common as far south as Glencoe (Foster *et al.*, 1995). Over the next 50 years, the occurrence of till exposures in the nearshore will likely extend farther south, possibly reaching as far south as Wilmette. As net erosion dominates the nearshore zone, the stability of shore structures will be threatened by downcutting of the glacial till and steepening of the upper part of the nearshore profile. Gillson Park will maintain a broad beach area due to the beach and nearshore sand being held by the shore structures on the north side of Wilmette Harbor. Beaches north of Gillson Park will be reduced in width and thickness.

SECTION 9 SUMMARY

9.1 This report presents new information concerning historical and ongoing nearshore coastal processes along the Illinois coast of Lake Michigan between Waukegan harbor and Wilmette Harbor. The following summarizes and integrates several key findings of this study.

1) The study area is divisible into three littoral cells that are secondary cells within a primary cell originating at Kenosha, Wisconsin and extending south to the Montrose peninsula on Chicago's north-side lakefront. The secondary cell divisions in the study area are: Waukegan Harbor to Great Lakes Harbor; Great Lakes Harbor to Forest Park Beach; and Forest Park Beach to Wilmette Harbor. Coastal management of the sand resources in the study area should be designed consistent with these secondary cell divisions.

2) Net erosion across the nearshore zone is prevalent along nearly all of the study area. Two areas of severe nearshore erosion each extend about 2 miles downdrift of Waukegan Harbor and Great Lakes Harbor, respectively. The nearshore erosion downdrift of Great Lakes Harbor is the most severe in the study area. Here there has been a near-total loss of nearshore sand. Maximum rates of till downcutting between 1974 and 1994 range from 0.19 ft/yr to 0.35 ft/yr. These rates are comparable to rates of downcutting previously documented downdrift of the harbor at St.Joseph, Michigan.

3) Bathymetric data collected in 1994 between Waukegan Harbor and Forest Park Beach provide a means of examining changes in bathymetry from 1974 to 1994. These changes can be compared to bathymetric comparisons for 1910 to 1974. In the last 20 years (1974-1994) there has been an expansion in the area of nearshore sand loss and an increase in rates of nearshore erosion. In addition, long-term (1910-1974) accretionary areas, such as around the perimeter of Great Lakes Harbor, have become erosional areas since 1974.

4) The most serious erosional problem in the study area is the loss of nearshore sand, downcutting of nearshore till, and the resultant deepening and steepening of the nearshore profile. At present, the most advanced stage of this process is along the Lake Bluff nearshore. Between 1910 and 1991, the slope from 0 to 5 ft LWD steepened by 882 percent; the slope from 0 to 10 ft LWD steepened by 118 percent. In the next 50 years, continued nearshore erosion could result in undermining and failure of many of the shore-defense structures in the study area.

5) A major and permanent loss of littoral sand from the study area and from the entire Illinois littoral stream resulted from 93 years (1889-1982) of deep-water disposal of sand dredged from Waukegan Harbor. The bin volume totals 2,492,754 cu yds. For the 87 years of near continuous offshore disposal (1889-1976), the total volume of offshore disposal was 2,407,358 cu yds. Based on this volume the 87-year average annual loss to the littoral system was 28,700 cu yds/yr.

6) Limited natural bypass of Waukegan Harbor occurred during the interval 1910-1974 and is recorded by an accretional lobe downdrift of the harbor entrance channel. A volume estimate for this accretion lobe is 1.6 million cu yds. For the 64-year record, the average annual accretion by natural bypass was 25,000 cu yds/yr.

7) Artificial bypass of dredge spoil from Waukegan Harbor first occurred in 1977 and has been the standard practice since 1984. The total volume of artificial bypass from 1977 through 1994 is 578,647 cu yds. In 1977 the spoil was placed just south of the south jetty. Since 1984 the spoil has been placed in a designated nearshore disposal area. For the 10 years of continuous artificial bypass (1984-1994), the total volume bypassed was 448,647 cu yds. This is an average annual contribution to the littoral stream of 44,900 cu yds/yr.

8) Waukegan Harbor was constructed in a setting of net accretion at the downdrift end of a prograding beach-ridge plain. This is a setting unique among the Federal harbors in southern Lake Michigan. If Waukegan Harbor had not been built, much of the accretion on the updrift side of this harbor would have occurred naturally as part of the beach-ridge plain accretion and southward growth. Two detrimental impacts are associated with the harbor. First, the harbor construction halted the southward advance of the beach-ridge plain and prevented the beach-ridge plain accretion that would have occurred downdrift of the harbor location. Second, downdrift littoral sediment starvation associated with the harbor contributed to severe nearshore erosion at Waukegan and North Chicago.

9) Great Lakes Harbor has trapped about 1.1 million cu yds of littoral sediment inside the area protected by the harbor breakwaters. These breakwaters were constructed in 1923. Based on sediment budget calculations, the primary source of this sediment was likely derived from nearshore erosion occurring between Waukegan Harbor and Great Lakes Harbor. Approximately 92 percent of this accretion occurred prior to 1976. The rate of infilling has been decreasing with time, and the harbor is possibly reaching, or has reached, its infill capacity for existing coastal conditions.

10) Great Lakes Harbor was likely a near-total barrier to littoral drift for several years following the harbor construction. However, natural bypass of Great Lakes Harbor was occurring at least by 1974. This is documented by a comparison of 1910 and 1974 bathymetry and the development of an accretion wedge on the harbor perimeter. This perimeter accretion was a sand bridge for natural bypass. Bathymetric data from 1994 indicate that between 1974 and 1994 net erosion occurred along most of this former accretion wedge. This net erosion occurred despite the updrift supply of littoral sediment from artificial bypass of Waukegan Harbor. The transition to net erosion is interpreted as a lake-bottom response to a deficit of littoral sediment supply.

11) As of 1994, the major area of littoral sediment entrapment in the study area is Forest Park Beach at Lake Forest. Accretion has been ongoing since the project was completed in 1987. A sand bridge for natural bypass is building southward around the lakeward perimeter of the project. The sand bridge has reached around two thirds of the facility. Net accretion in this accretion wedge and in the beach cells at the facility from 1987 to 1994 totaled 65,600 cu yds (an average annual net accretion of 9,400 cu yds/yr). Since natural bypass is occurring at Great Lakes Harbor, the sediment source for the accretion at Forest Park Beach can be attributed to a combination of (1) nearshore erosion occurring updrift as far north as Waukegan Harbor, (2) artificial bypass of sand dredged from Waukegan Harbor, and (3) sand from updrift of Waukegan Harbor that can naturally bypass this harbor. The erosion that occurred between 1974 and 1994 on the perimeter of Great Lakes Harbor demonstrates that accretion on the perimeter of Forest Park Beach could also begin to erode if the updrift supply of littoral sediment is diminished.

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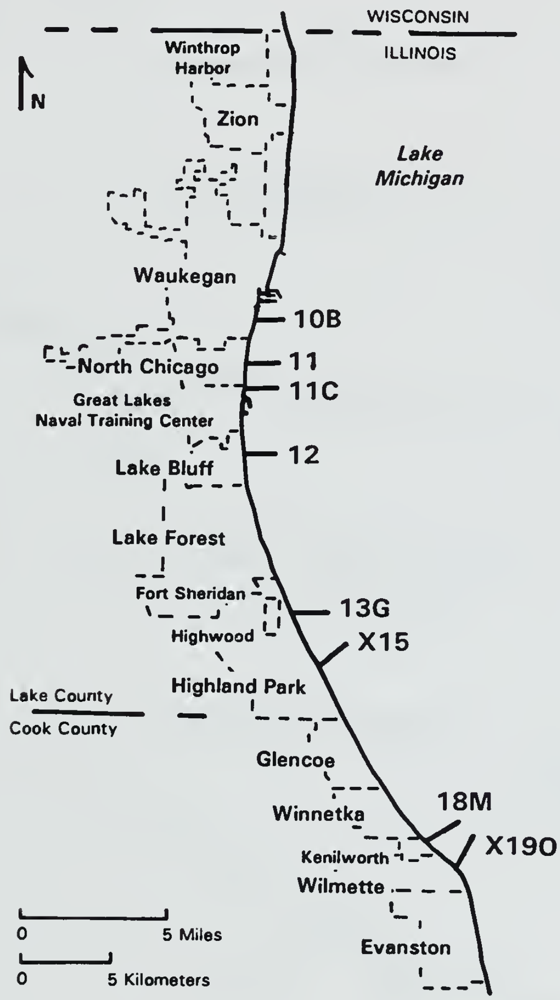
ATTACHMENTS

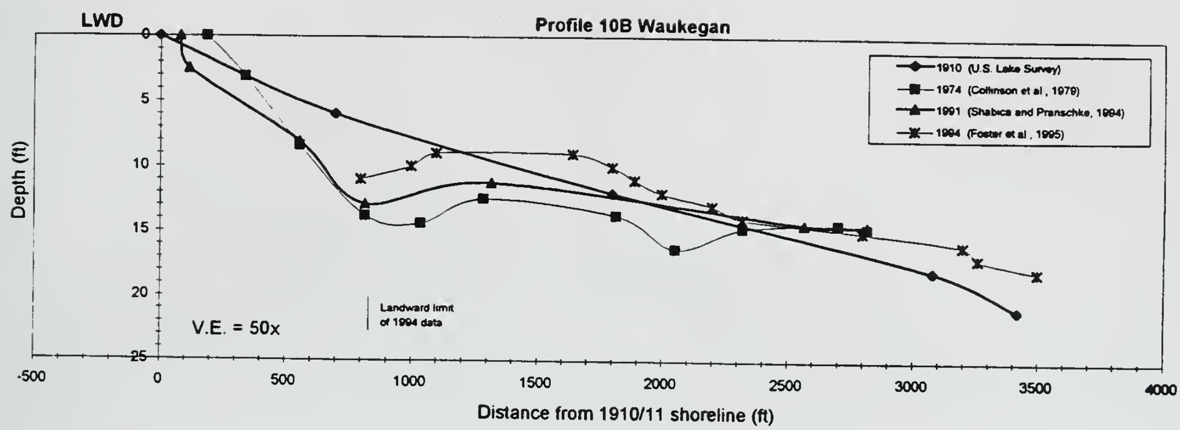
The following sets of attachments provide data related to eight nearshore profiles in the study area used in recent reports by Shabica *et al.* (1991) and Shabica and Pranschke (1994) to provide inventories of beach and nearshore sand resources. The sets of attachments are:

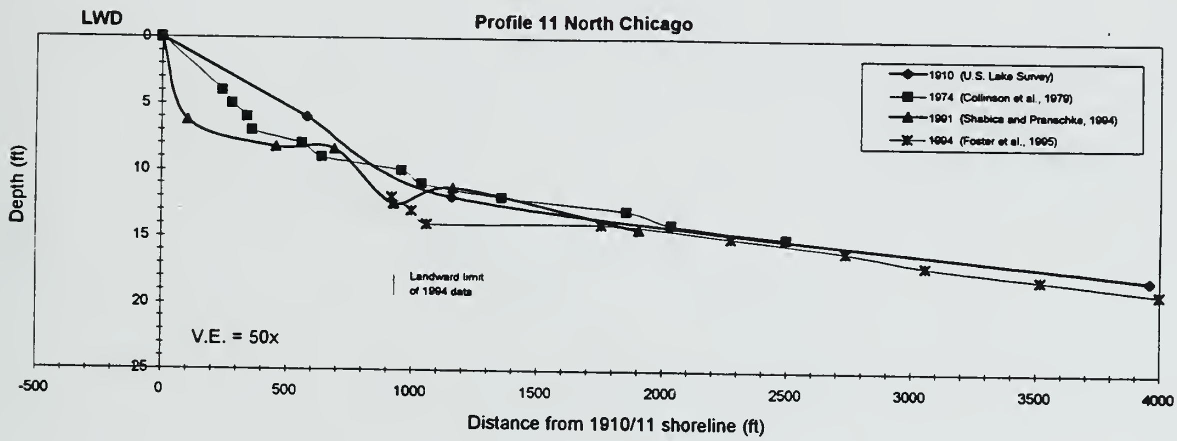
Attachment 1: Profile comparisons
Attachment 2: Tables of vertical and horizontal profile changes
Attachment 3: Tables of nearshore depths and changes in depth
Attachment 4: Tables of nearshore slope calculations

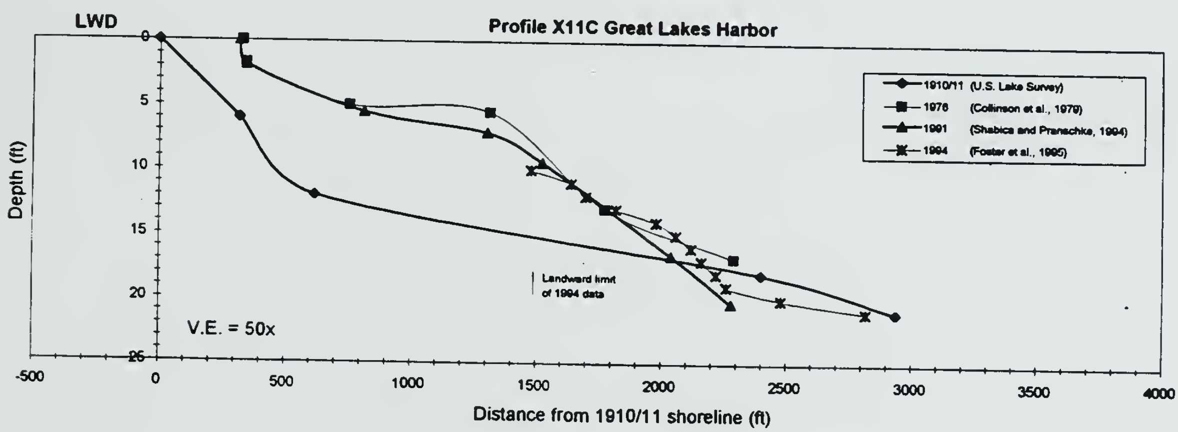


Index map showing location of nearshore profiles within the study area reported by Shabica and Pranschke (1994).

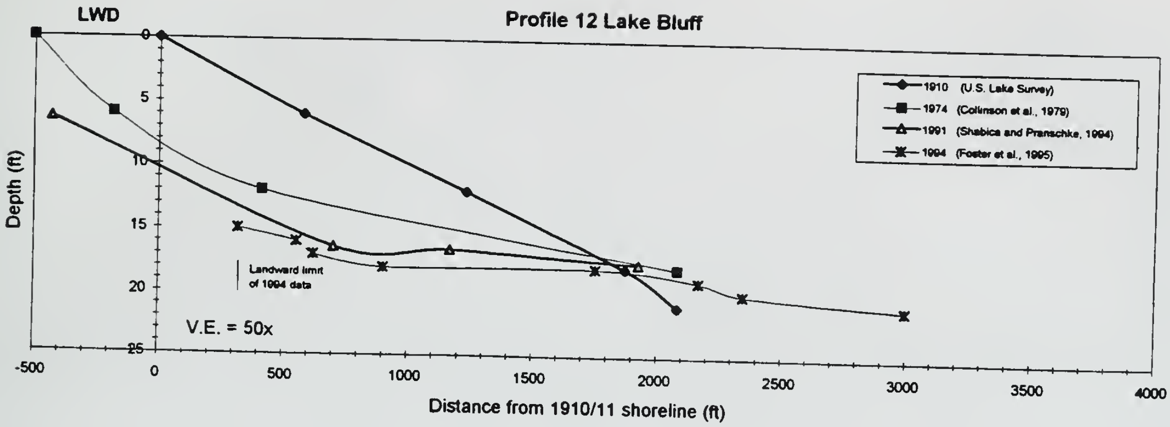
Attachment 1: Profile comparisons.

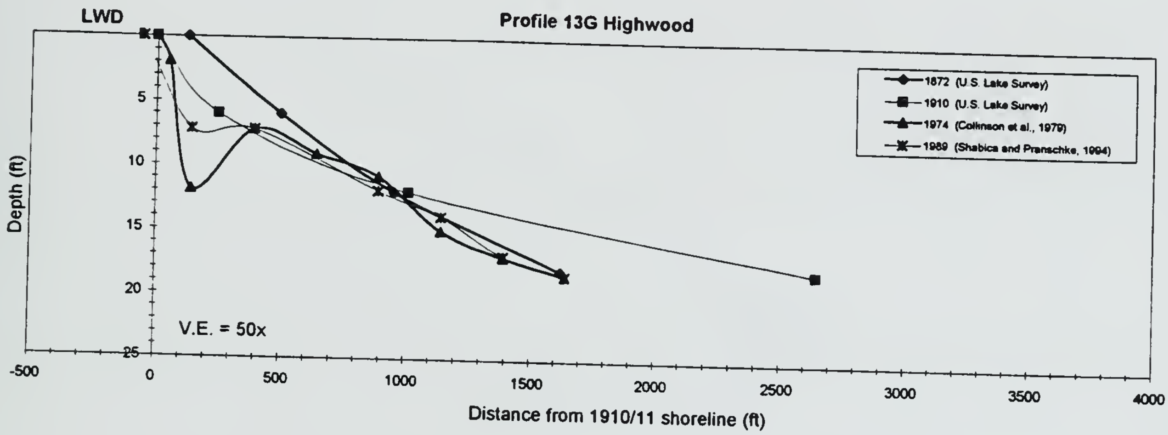


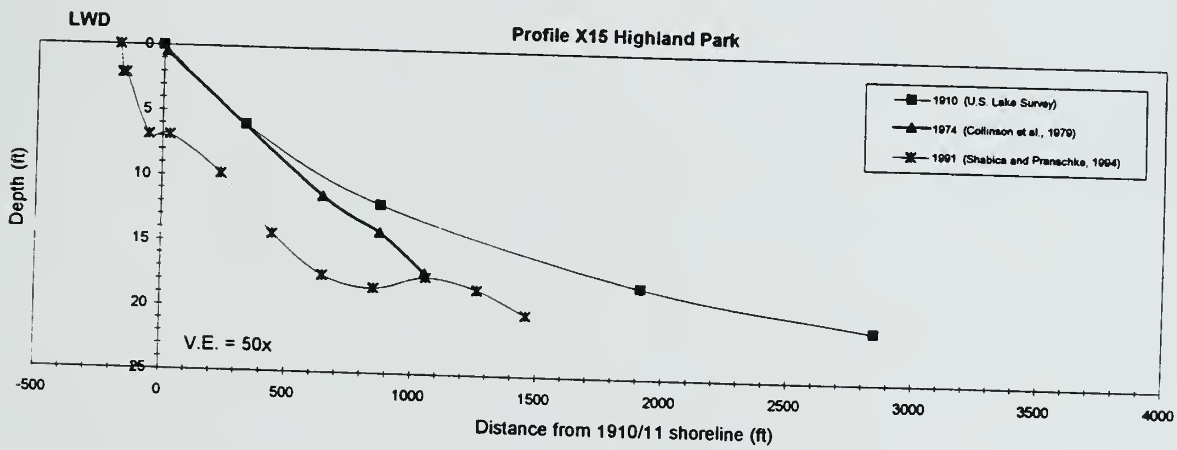




Attachment 1 (cont.).







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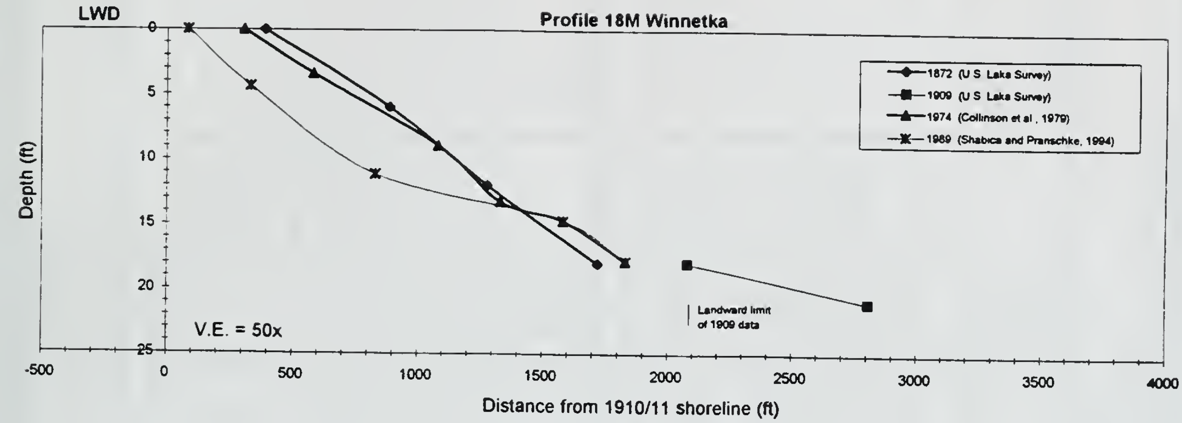

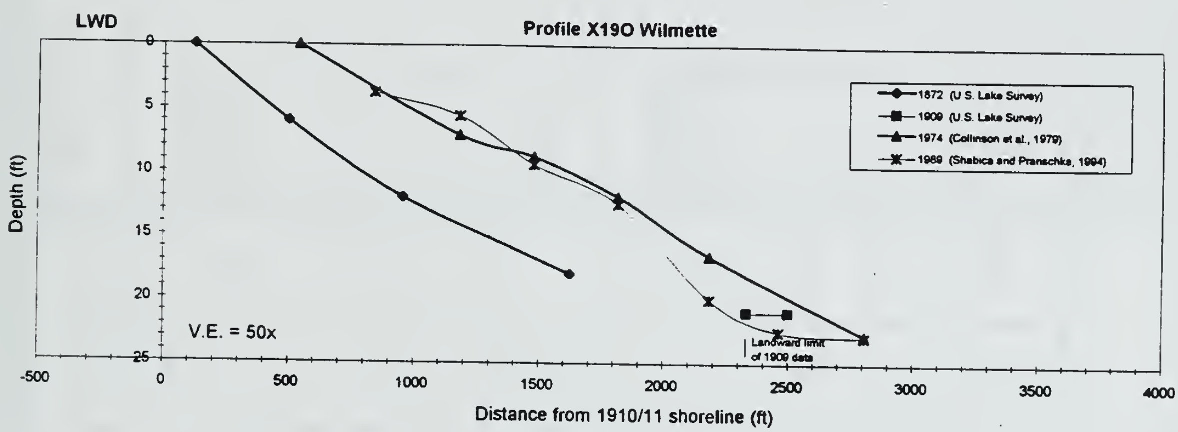

Attachment 2: Tables of vertical and horizontal profile changes.

Profile 10b: Waukegan

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994	
Vertical Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	--	--	--	--	--	--
5	-1.2	-0.02	-3.4	-0.20	--	--
10	-4.7	-0.07	+0.5	+0.03	+2.2	+0.73
15	-2.5	-0.04	+2.4	+0.14	--	--
20	--	--	--	--	--	--
Maximum Change	-7.2 at 14.5 ft depth	-0.11	-3.6 at 3.5 ft depth	-0.21	+2.8 at 9 ft depth	+0.93
Horizontal Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	+190	+3.0	-110	-6.5	--	--
5	-160	-2.5	-110	-6.5	--	--
10	-790	-12.3	+10	+0.6	--	--
15	-510	-8.0	(A)	--	--	--
20	--	--	--	--	--	--
Maximum Change	-1070 at 12.5 ft	-16.7	+510 at 12.5 ft	+30.0	+590 at 11 ft	+196.7

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Profile 11: North Chicago

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994	
Vertical Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	0	0	0	0	--	--
5	-2	-0.03	-4.1	-0.24	--	--
10	+0.7	+0.01	-0.5	-0.03	--	--
15	+0.1	+0.002	(E)	--	--	--
20	--	--	--	--	--	--
Maximum Change	-3.5 at 7 ft depth	-0.05	-4.9 at 6.3 ft depth	-0.29	-2.9 at 14 ft depth	-0.97
Horizontal Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	0	0	0	0	--	--
5	-190	-3.0	-250	-14.7	--	--
10	+80	+1.2	-180	-10.6	--	--
15	+20	+0.3	(E)	--	(A)	--
20	--	--	--	--	--	--
Maximum Depth	+350 at 13 ft depth	+5.5	-270 at 13 ft depth	-15.9	-720 at 14 ft depth	-240.0

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Attachment 2 (cont.).

Profile x11c: Great Lakes Harbor

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994	
Vertical Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	(A)	--	(E)	--	--	--
5	+7.7	+0.12	0	0	--	--
10	+5.5	+0.09	-0.5	-0.03	(E)	--
15	+1.9	+0.03	-0.5	-0.03	+2	+0.67
20	--	--	-3.5	-0.21	(A)	--
Maximum Change	+9.2 at 5 ft depth	+0.14	-3.6 at 20.5 ft depth	-0.21	+2.1 at 14.5 ft depth	+0.70
Horizontal Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	+325	+5.1	-10	-0.6	--	--
5	+500	+7.8	0	0	--	--
10	+1140	+17.8	-30	-1.8	(E)	--
15	+590	+9.2	-90	-5.3	+130	+43.3
20	--	--	(E)	--	+210	+70
Maximum Change	+1120 at 11 ft depth	+17.5	+530 at 5.5 ft depth	+31.2	+280 at 20.5 ft depth	+93.3

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Profile 12: Lake Bluff

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994	
Vertical Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	(E)	--	--	--	--	--
5	-5	-0.08	(E)	--	--	--
10	-8.8	-0.14	-2	-0.12	--	--
15	-3.5	-0.05	-1.8	-0.11	-1.8	-0.60
20	+2.3	+0.04	(A)	--	--	--
Maximum Change	-8.8 at 10 ft depth	-0.14	-3.2 at 17 ft depth	-0.19	-1.5 at 18 ft depth	-0.50
Horizontal Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	-500	-7.8	--	--	--	--
5	-750	-11.7	-200	-11.8	--	--
10	-900	-14.1	-900	-52.9	--	--
15	-350	-5.5	-360	-21.2	-200	-66.7
20	(A)	--	(A)	--	--	--
Maximum Change	-900 at 10 ft depth	-14.1	-860 at 16.5 ft depth	-50.6	-1160 at 17 ft depth	-386.7

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Attachment 2 (cont.).

Profile 13g: Highwood

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994	
Vertical Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	(E)	--	0	0	(E)	--
5	-4.2	-0.07	-2.9	-0.17	0	0
10	-1.6	-0.03	-0.8	-0.05	-0.5	-0.17
15	(A)	--	(E)	--	-0.8	-0.27
20	(A)	--	(E)	--	--	--
Maximum Change	-4.2 at 5 ft depth	-0.07	-7.8 at 12 ft depth	-0.46	+4.8 at 7 ft depth	+1.60
Horizontal Change[1]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	-110	-1.7	0	0	-60	-20.0
5	-250	-3.9	-105	-6.2	0	0
10	-130	-2.0	+105	+6.2	-80	-26.7
15	+510	+8.0	+630	+37.1	+95	+31.7
20	(A)	--	(E)	--	--	--
Maximum Change	+1020 at 18 ft depth	+15.9	-1080 at 18 ft depth	-63.5	+130 at 7.5 ft depth	+43.3

[1] "-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Profile x15: Highland Park

ENDING DEPTH	INTERVAL					
	1910-1974		1974-1991		1991-1994[1]	
Vertical Change[2]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	0	0	(E)	--	--	--
5	0	0	(E)	--	--	--
10	-1	-0.01	-6	-0.35	--	--
15	-2.6	-0.03	-9	-0.53	--	--
20	(E)	--	--	--	--	--
Maximum Change	-4.2 at 17.3 ft depth	-0.07	-7 at 18.5 ft depth	-0.41	--	--
Horizontal Change[2]						
	Total	Per Year	Total	Per Year	Total	Per Year
0	0	0	-170	-10.0	--	--
5	0	0	-360	-21.2	--	--
10	-80	-1.0	-305	-17.9	--	--
15	-410	-4.9	-460	-27.1	--	--
20	(E)	--	--	--	--	--
Maximum Change	-600 at 17.5 ft depth	-9.4	-460 at 15 ft depth	-27.1	--	--

[1] No 1994 data available.
[2] "-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Attachment 2 (cont.).

Profile 18m: Winnetka

ENDING DEPTH	INTERVAL			
	1872-1974		1974-1989	
Vertical Change[1]				
	Total	Per Year	Total	Per Year
0	(E)	--	(E)	●
5	-1	-0.01	-4.1	-0.27
10	0	0	-5.2	-0.35
15	+0.8	+0.01	0	0
20	--	--	--	--
Maximum Change	+1.6 at 16.6 ft depth	+0.02	-5.3 at 11 ft depth	-0.35
Horizontal Change[1]				
	Total	Per Year	Total	Per Year
0	-80	-0.8	-200	-13.3
5	-70	-0.7	-350	-28.●
10	0	0	-420	-28.0
15	+110	+1.2	0	0
20	--	--	--	--
Maximum Change	+120 at 18 ft depth	+1.2	-460 at 9 ft depth	-30.7

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Profile x19o: Wilmette

ENDING DEPTH	INTERVAL			
	1872-1974		1974-1989	
Vertical Change[1]				
	Total	Per Year	Total	Per Year
0	+6.6	+0.06	--	--
5	+7.2	+0.07	+1.2	+0.08
10	+8.3	+0.08	-0.8	-0.05
15	(A)	--	-2	-0.13
20	--	--	-3.5	-0.23
Maximum Change	+8.3 at 10 ft depth	+0.08	-3.6 at 22 ft depth	-0.24
Horizontal Change[1]				
	Total	Per Year	Total	Per Year
0	+410	+4.0	--	--
5	+560	+5.5	+105	+7.0
10	+770	+7.6	-80	-5.3
15	+840	+8.2	-100	-6.7
20	(A)	--	-340	-22.7
Maximum Change	+870 at 11.5 ft depth	+8.5	-380 at 21.5 ft depth	-25.3

[1]"-": erosion; "+": accretion.
"--": no comparison could be made.
"(A)": accretion occurred but actual amount indeterminate.
"(E)": erosion occurred but actual amount indeterminate.

Attachment 3: Tables of nearshore depths and changes in depth.

YEAR	Distance lakeward of 1910/11 shoreline (feet)				
	100	200	300	400	500
Profile 10b - Waukegan					
1911	3.3	3.3	7.9	8.8	5.1
1974	0	0.9	7.9	7.9	8.0
1991	7.9	3.3	7.9	6.1	7.4
Profile 11 - North Chicago					
1911	7.9	2.1	3.3	6.1	5.1
1974	3.3	3.3	3.3	7.2	7.4
1911	6.1	3.3	7.9	7.9	8.0
Profile x11c - Great Lakes Harbor					
1911	7.9	8.8	3.3	7.9	8.0
1974	L	L	L	7.2	8.0
1991	L	L	L	2.3	8.0
Profile 12 - Lake Bluff					
1911	7.9	2.1	3.3	6.1	5.1
1974	8.8	3.3	10.8	10.8	12.3
1991	11.1	11.9	12.8	13.7	14.6
Data landward of 1910/11 shoreline					
1974	6.8	5.7	3.8	1.9	0
1991	9.3	8.4	7.5	6.6	U

YEAR	Distance lakeward of 1910/11 shoreline (feet)				
	100	200	300	400	500
Profile 13g - Highwood					
1872	L	1.2	7.9	4.4	6.0
1910	7.9	8.9	3.3	7.2	8.0
1974	7.9	10.8	8.9	7.2	8.0
1989	3.3	7.2	1.2	7.9	8.2
Profile x15 - Highland Park					
1974	7.9	8.9	5.4	6.1	7.4
1974	7.9	3.7	5.5	7.2	6.9
1991	7.9	3.3	11.2	13.4	15.2
Data landward of 1910/11 shoreline					
1991	3.3				
Profile 18m - Winnetka					
1872	L	L	L	6.1	1.3
1974	L	L	0	3.3	2.4
1989	0.8	2.0	3.3	5.3	6.6
Profile x19c - Wilmette					
1872	L	1.2	2.8	4.4	6.0
1974	L	L	L	L	L
1989	U	U	U	U	U

"0" indicates depth was 0 feet LWD.
"L" indicates area was land above 0 feet LWD.
"U" indicates elevation is unknown.

Attachment 4: Tables of nearshore slope calculations.

Profile 10b: Waukegan, South Cummings Avenue			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:117	1:187	1:152
1974	1:43	1:47	1:45
1991	1:66	1:58	1:62
Percent Change 1910-1991	177	322	245

Profile 11: North Chicago FBI Range			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:97	1:97	1:97
1974	1:57	1:141	1:99
1991	1:16	1:174	1:95
Percent Change 1910-1991	606	56	102

Profile x11c: GLTC North			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:53	1:51	1:52
1974	1:100	1:168	1:134
1991	1:104	1:190	1:147
Percent Change 1910-1991	51	27	35

Profile x12: Lake Bluff, Arden Shore			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:97	1:109	1:103
1974	1:53	1:105	1:79
1991	1:11	1:163	1:87
Percent Change 1910-1991	882	67	118

Profile 13g: Highwood Water Works			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:42	1:142	1:92
1974	1:12	1:12	1:12
1989	1:27	1:157	1:92
Percent Change 1910-1989	156	90	0

Profile x15: Highland Park, Ravine			
Year	0-5 ft	5-10 ft	0-10 ft
1910	1:56	1:92	1:74
1974	1:57	1:65	1:61
1991	1:19	1:79	1:49
Percent Change 1910-1991	295	116	151

Profile 18m: Winnetka, Elder Lane			
Year	0-5 ft	5-10 ft	0-10 ft
1872	1:83	1:67	1:75
1974	1:87	1:73	1:80
1989	1:57	1:79	1:68
Percent Change 1872-1989	146	85	110

Profile x19c: Wilmette, Gillson Park			
Year	0-5 ft	5-10 ft	0-10 ft
1872	1:63	1:77	1:70
1974	1:90	1:126	1:108
1989	1:106	1:102	1:104
Percent Change 1872-1989	59	75	67